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NEW WAYS

Tiltrotor Aircraft and Magnetically Levitated Vehicles

J952-93

CONGRESS OF THE UNITED STATES OFFICE OF TECHNOLOGY ASSESSMENT

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Foreword

Flying on a commercial jet is now the fastest way for the public to travel between most cities in the United States. But travelers spend much of their trip time getting to or from the airport, at the terminal, or in the airplane while it sits on the ground. Magnetically levitated (maglev) vehicles and tiltrotor aircraft are among the new and distinctly different technologies that have been proposed to help travelers go from origin to destination quicker than conventional airlines or Amtrak, on trips up to about 500 miles.

In recent years, Congress has supported both military tiltrotor development and research into maglev technologies, although budget constraints have threatened this funding each year. At the request of the House Committee on Appropriations, OTA assessed what is currently known about tiltrotor and maglev, and what roles these and other advanced technologies could play in improving intercity transportation. The late Senator John Heinz had also asked OTA to study the construction costs of various high-speed rail and maglev systems.

Common issues for these systems include their possible contributions to improving mobility in congested corridors, U.S. technology leadership, the Federal role in transportation research and development, and institutional and community barriers to major, new infrastructure programs. Moreover, some Federal financing is likely to be required if commercial maglev or tiltrotor technologies are to be developed by U.S. industry over the next decade.

Congress will need to clarify its objectives for supporting or encouraging these technologies before it can make wise decisions on when or whether to undertake substantial, long-term Federal programs in support of either or both of them. This report identifies several funding and management options for consideration if such goals are established.

OTA thanks the many government, industry, and citizen participants who contributed generously to this study through workshop panels, interviews, reviews, and other means of sharing their knowledge and experience with us. Their participation does not necessarily represent endorsement of the contents of the report, for which OTA bears sole responsibility.

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CHAPTER I

Summary

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CHAPTER I
Summary

On almost any journey between major cities in the United States, travelers encounter traffic jams on busy roads and at airports. Magnetically levitated (maglev) vehicles and tiltrotor aircraft are among the technologies that could improve passenger mobility at large terminals and in the most crowded intercity corridors in the United States in the long term. However, like all new transportation systems, both tiltrotor and maglev will be expensive to develop and establish, and some form of Federal support will be necessary if either one is to have a substantial role in intercity passenger service. Furthermore, complementary Federal policies, programs, and standards must be developed and implemented, if these technologies are to help resolve any of the congestion problems besetting transportation. Budget constraints and the uncertainties inherent in deciding how much and what type of additional Federal investment to make in these two technologies confront Congress with difficult decisions. At the request of the House Committee on Appropriations, OTA has assessed what is currently known about tiltrotor and maglev and laid out findings and options for Congress to consider.

The Decisionmaking Framework

Maglev vehicles, which resemble either monorail cars or sleek trains, are lifted and propelled above special guideways by magnetic forces (see photos) and are probably capable of traveling at top speeds of close to 300 miles per hour. The maglev propulsion and guideway are quite unlike those of steel-wheel trains, which are mechanically driven along rails, and a maglev system would require entirely new infrastructure, as well as new vehicles. In contrast, high-speed rail technology is well developed in other countries and could be implemented relatively quickly in this country on existing railroad rights-of-way if tracks are upgraded appropriately. However, proponents assert that maglev systems are the most promising and exciting new technology for making intercity travel faster and more comfortable and energy efficient in the more distant future.

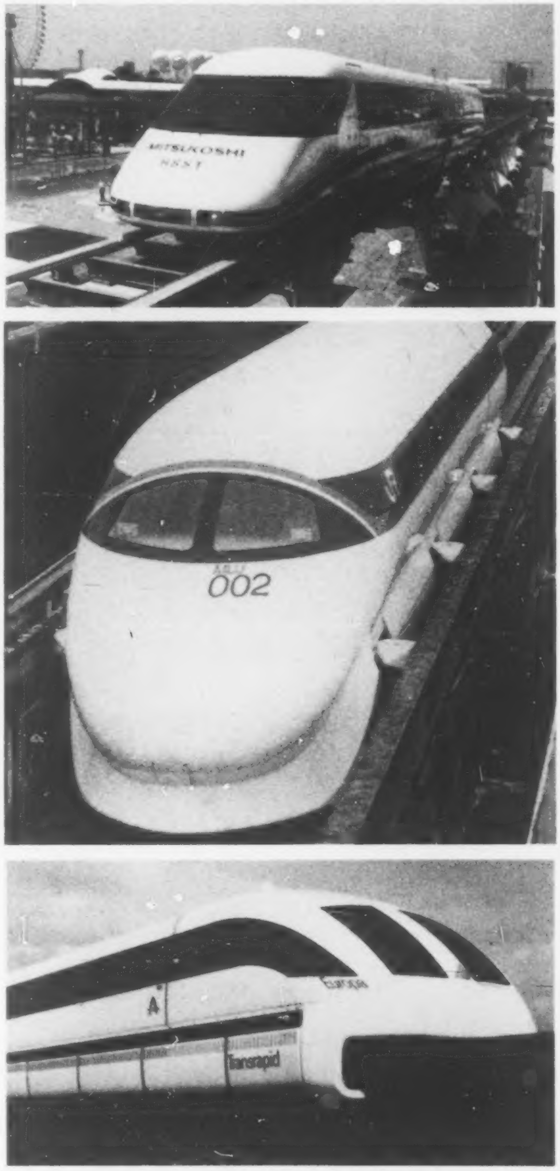

Photo credit: Magnetschnellbahn AG, Railway Technical Research Institute, HSST Corp.

Three major maglev systems are being developed: the high-speed German Transrapid and Japanese MLU, and the low-speed Japanese HSST.

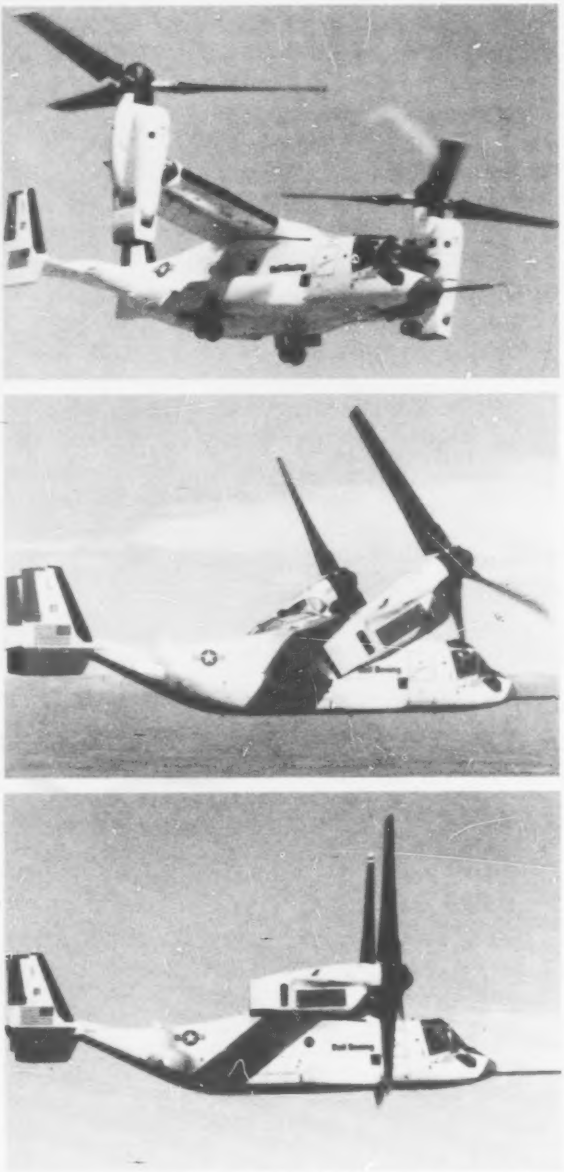

Photo credit: Bell Helicopter Textron, Inc. and Boeing Helicopters

The V-22 Osprey tiltrotor can fly with its rotors in any position from vertical to horizontal.

Tiltrotor aircraft, developed and tested for a variety of missions by the National Aeronautics and Space Administration (NASA) and the Department of Defense (DOD), can fly like both a helicopter and an airplane. Pivoting engine/rotor assemblies, mounted on each wingtip, permit a tiltrotor to takeoff and land like a helicopter at sites as small as the roof of a parking garage when the rotor thrust is vertical. When the rotors are tilted forward 90 degrees, the tiltrotor can cruise as fast as a propeller-driven commuter airplane (see photos). Supporters claim that these characteristics would allow commercial tiltrotors to offer significant door-to-door time savings compared with similar trips on jetliners and to add capacity to congested airports because tiltrotors do not require runways to operate.

Although distinctly different, maglev and tiltrotor systems have several common policy and market issues, including the following:

- The busiest travel corridors over distances between 100 and 500 miles are the primary target markets for each. Time-sensitive service would be their initial niches in these markets.
- Tiltrotor and maglev systems would expand domestic transportation capacity, and might help relieve congestion in other modes.
- Western European and Japanese companies are developing commercial maglev and tiltrotor-like systems, and see the United States as a key market.
- Additional public support for research, development, and demonstration is necessary, if U.S. industry is to seriously consider producing commercial maglev or tiltrotor technology in the next decade. The amount of new funding required would exceed $200 million for commercial tiltrotor and substantially more for maglev.
- Regardless of where the technology is developed, each system must overcome institutional hurdles to succeed commercially in the United States—difficulty in financing, Federal safety regulations that are not yet established, local community objections to the impacts of new transportation operations and infrastructure, and the need to compete with established transport modes.

Despite these commonalities, tiltrotor and maglev differ in many ways. For instance, although they would compete directly in some market areas, each would be likely to develop its own specialty markets. Landing facilities designed for tiltrotors are relatively inexpensive to build;[1] however, tiltrotors, with their vertical flight capabilities, cost more to produce, operate, and maintain than comparable conventional airplanes (but cost substantially less than helicopters). A tiltrotor network's key advantage is avoiding airport and some road congestion. The aircraft's strength is providing fast point-to-point service between relatively small transportation market points and independent of runway locations. In contrast, guideway right-of-way, materials, and construction for high-speed trains, whether maglev or rail, will generate most of the costs, while operating expenses per passenger are (or might be, in the case of maglev) lower than those for aircraft for short trips. Maglev (and high-speed trains) are best suited for routes with large passenger volumes, where frequent departures would allow them to compete with airlines and possibly attract time-sensitive travelers from other modes.

While tiltrotor and maglev could both serve intercity commercial travel, each has the potential for other, differing applications. Existing tiltrotors have been developed primarily for military missions, and similar aircraft could fill other public roles, such as emergency evacuation, or serve industry needs—offshore oil rig support, for example. Maglev trains already carry passengers on short, low-speed transit lines in Germany and England, and regional transit, commuter, and light parcel service might be feasible if maglev's potential for low maintenance costs can be realized.

The U.S. technical base is also distinctly different for each of these technologies. The United States has had Federal programs to develop and test tiltrotor and other advanced vertical takeoff and landing (VTOL) aircraft for decades. Although the military tiltrotor (V-22 *Osprey*) design is unsuitable for most commercial transport applications, civilian tiltrotor development would benefit from the engineering and operational experience of the military program. The support of these Federal programs has provided U.S. industry with a 5-year lead worldwide in being able to produce commercial tiltrotors, if a Federal decision is made to pursue such a goal. On the other hand, the Federal Government has invested little in high-speed ground transportation research during the past 15 years. (A decade-long Federal high-speed ground transportation research and development (R&D) program ended in 1975.) Western European and Japanese industries have roughly a 5- to 10-year lead in bringing maglev to the market. They have also been producing and operating high-speed rail systems for years.

Issues

Tiltrotors and maglevs are each a part of broader transport categories, VTOL aircraft and high-speed ground transport, respectively. Neither category is used much in commercial passenger service in the United States, although high-speed trains are widely used in Europe and Japan, where these systems are expanding. Moreover, both tiltrotors and maglevs have technical development requirements that must be met before a commercial system could be implemented.[2] While both new technologies are likely to have performance advantages over other types of VTOL or high-speed rail, this promise alone is not enough to assure their success in competition with other forms of transportation. Potential operators and entrepreneurs for each must also face and overcome the significant institutional and community barriers to establishing new transportation systems. To cite just one example, tiltrotors and maglevs have significantly different design and performance characteristics than conventional aircraft and rail systems, and current Federal safety regulations must be developed or changed to address each of these new technologies.

Maglev and High-Speed Rail Systems

Across the country, States, local authorities, and private groups have seriously investigated the potential of high-speed ground vehicles, both maglev and rail, to meet their transportation needs. In each case, the investigating group has planned on purchasing currently available foreign vehicle technology and using U.S. expertise for guideway development and construction. However, because public programs have not been available to fund infrastructure development, an intercity, high-speed ground corridor has yet to be successfully financed in the United States.

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[1] A metropolitan vertiport capable of handling 1 million passengers annually would cost around $40 million to establish.

[2] In the context of ground transportation, speeds above 150 miles per hour (mph) are considered "high." Amtrak's Metroliner operates at 125 mph on certain track segments between Washington, DC, and New York City.

Technology Development

Maglev technology is being developed primarily in Japan and Germany, where major, long-term, government-supported research programs are under way. A German consortium, formerly known as Transrapid International,[3] has developed a maglev system to the preproduction prototype stage and tested it extensively at a facility in Northwest Germany at a cost of over $1 billion. The first U.S. commercial use of maglev, scheduled for Orlando, Florida, beginning in 1995, will use Transrapid technology. The Japanese Railway Technical Research Institute, supported by the recently privatized Japanese Railways, has invested $1 billion in developing a maglev system. A 27-mile test facility is under development for possible inclusion in a future revenue line between Tokyo and Osaka. An extensive 4-year test of the system is expected to commence in 1993 at a total cost of around $3 billion with earliest commercial service feasible by 2000. The other major Japanese system is the HSST, originally sponsored by Japan Airlines, but now a separate, private enterprise. Somewhat similar to the German Transrapid design,[4] the HSST has been demonstrated extensively, but only on tracks shorter than 1 mile. The HSST uses a lighter and less costly guideway than other maglev concepts, but the maximum design speed is less than 200 mph.

These efforts overseas have raised concerns that the United States is falling further behind in an important new technology. In 1990 the National Maglev Initiative (NMI) was created—a 2-year, $30 million program now in its first phase, to evaluate the engineering, economic, environmental, and safety research needs for a U.S. maglev system. The three-organization NMI team—comprised of staff from the Department of Transportation (DOT), the U.S. Army Corps of Engineers, and the Department of Energy—is slated to report its findings in fall 1992 and to include among them a recommendation on whether to pursue future maglev development domestically. The results of NMI investigations will help in evaluating foreign maglev performance and in deciding whether or not to commit major public funds for a U.S. maglev program. In conjunction with NMI, DOT is also examining high-speed rail technologies for their potential contributions to mobility in the United States.

Sustained funding through completion of NMI's initial phase will be needed if the team is to develop the information Congress must have to decide how much and what kinds of future support it wishes to provide. The NMI study findings are not likely to be available in time for fiscal year 1993 transportation appropriations deliberations. Consequently, Congress may wish to provide follow-on funding for a transition year for the most promising Federal efforts, while the near-term Federal role in maglev technology development is debated.

Research efforts to reduce the costs of materials and construction, address the health effects, and limit the environmental impacts are critical to the future of maglev. Communication, automation, and passenger safety investigations would benefit a variety of maglev designs, and understanding the health effects of electromagnetic fields is important for the future of all electrically powered transportation systems.

Maglev Implementation

Both maglev and high-speed rail will need new, grade-separated guideways[5] for high-speed service, but steel-wheel trains could also operate at low speeds on existing tracks that are in good condition. Maglev vehicles and guideways are intrinsically linked, and the German and Japanese prototype maglev vehicles each have unique, incompatible guideways. While it is too early to establish standards for maglev, uniform guideways will be crucial to bring costs down if intercity maglev is ever to be established on a nationwide scale. Intermodal connections and adequate access to stations from other modes of transportation are also important for success.

The relative intercity market potential of maglev and high-speed rail will depend on factors specific to each route, such as right-of-way alignment, number of stops, real estate costs, and projected ridership. However, only high-speed rail technology is proven and ready for intercity service now. For the future, maglev promises faster speeds, quicker acceleration, the ability to ascend steeper grades, less noise, and better energy efficiency than rail at similar high speeds.

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[3] The consortium has been expanded and renamed Magnetschnellbahn AG.

[4] The HSST uses a suspension concept similar to Transrapid's, but uses a different propulsion system.

[5] Grade-separated refers to elevating or depressing tracks or a guideway above or below roads, bridges, or other structures.

Maglev and high-speed trains would generate a variety of social advantages and costs that must be considered in public policies for these technologies. High-speed trains operating on grade-separated tracks are very safe; no passengers have been fatally injured in either Japanese or French rail systems in high-speed service. High-speed rail and maglev are relatively energy efficient at their operating speeds and, because they use electricity for power, are not dependent on petroleum and do not degrade the air quality in the areas where they operate.[6] These are societal benefits, however, and do not at present constitute substantial economic incentives to a potential operator other than direct costs for fuel. Maglev proposals, like those for any new infrastructure, will encounter environmental permitting requirements and are likely to generate concern over noise under some conditions.

At this point, then, the largest cost difficulty for maglev implementation lies in financing rights-of-way and guideway construction. Revenues received on bonds issued for some high-speed, intercity rail facilities are exempted from Federal income tax, but because State laws limit many types of tax-exempt bonds,[7] tax incentives have so far not made a difference for would-be high-speed rail or maglev developers.[8] Tax-exempt bonds for other purposes are readily available to investors, and these circumstances are likely to continue to make private sector financing difficult unless State laws are changed. Proposed highway reauthorization legislation for 1991 would make it easier for States to make highway rights-of-way available to other surface transportation systems, including high-speed rail and maglev, and would permit funding from the Highway Trust Fund under certain circumstances.

Tiltrotor Systems

Tiltrotor's commercial strengths are its abilities to avoid ground access or airport congestion by providing point-to-point service to conveniently located landing facilities, feeder flights into airports where runway capacity is saturated, and service to new points as necessary without the need for runways. Tiltrotor passengers and some aspects of the aviation system could benefit from these services. Individual airlines, however, see mostly risks and no additional profits over the status quo and have expressed little interest in pushing for commercial tiltrotor development.

Technology Development

NASA and DOD have investigated a wide range of advanced VTOL aircraft designs over the past four decades, and have concluded that tiltrotors hold strong promise for a variety of missions. The Federal Government has spent over $2.5 billion for XV-15 and V-22 tiltrotor development programs,[9] and private industry has invested another $200 million to $300 million on military tiltrotor technology.[10] Experts estimate that U.S. industry would have to inject around $1 billion to $1.5 billion more to produce a commercial tiltrotor.[11]

Given the market and implementation uncertainties for commercial tiltrotors, private industry and investors are not yet willing to commit the substantial funds needed to develop a commercial tiltrotor. The NASA/Federal Aviation Administration (FAA) civil tiltrotor missions and applications study[12] was completed to outline the actions necessary before such development could occur. The study report recommended an intensive 1-year planning effort followed by a 3-year tiltrotor research and technology demonstration program to enable industry and public authorities to decide ". . . whether creating a commercial tiltrotor system is technically feasible, economically attractive, and in the national interest."[13]

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[6] Coal is the primary fuel for U.S. electric powerplants, providing 57 percent of all electricity generated in 1987. Nuclear power is the source of 18 percent of U.S. electricity. Coal and nuclear fuel raise other environmental concerns. See U.S. Congress, Office of Technology Assessment, *Electric Power Wheeling and Dealing: Technology Considerations for Increasing Competition*, OTA-E-409 (Washington, DC: U.S. Government Printing Office, May 1989).

[7] U.S. Congress, Office of Technology Assessment, *Rebuilding the Foundations: A Special Report on State and Local Public Works Financing and Management*, OTA-SET-447 (Washington, DC: U.S. Government Printing Office, March 1990), p. 58.

[8] Robert Cox, attorney, remarks at OTA Workshop on Maglev and Tiltrotor Transportation: System Concepts, Economics, and Regulatory Issues, Apr. 18, 1991.

[9] Boeing Commercial Airplane Group et al., *Civil Tiltrotor Missions and Applications Phase II: The Commercial Passenger Market*, prepared for National Aeronautics and Space Administration and Federal Aviation Administration, NASA CR 177576 (Seattle, WA: Boeing Commercial Airplane Group, February 1991).

[10] Federal Aviation Administration, Research, Engineering, and Development Advisory Committee, Tiltrotor Technology Subcommittee, *Report* (Washington, DC: June 26, 1990), p. 12.

[11] Philip C. Norwine, vice president, Commercial Market Development, Bell Helicopter Textron, remarks at OTA Workshop on Maglev and Tiltrotor Technologies: Research, Development, and Testing Needs and the Federal Role, Feb. 6, 1991.

If funding is available, the most important technology development priorities for a commercial tiltrotor program are improving rotor designs to reduce noise, ensuring appropriate cockpit equipment and procedures, and developing flight tests and any necessary equipment (such as a low-speed, air speed indicator) to permit steep flight paths to and from landing facilities. However, without an assured financing stream, larger tasks, such as quiet rotor design and flight testing, will not be undertaken.

Eurofar (a consortium of five European helicopter manufacturers) has completed design studies and anticipates funding for development of a civil tiltrotor demonstrator. Regardless of U.S. Federal and industry decisions regarding tiltrotor, Ishida, a Japanese company, may sell the first high-speed VTOL in the civil market. However, the aircraft Ishida is developing uses a tiltwing, rather than a tiltrotor, and development and production are occurring in the United States.

Tiltrotor Implementation

The timesavings of tiltrotor service, which could be substantial, hinge on well-situated vertiports. Since tiltrotors do not need runways, 5-acre or smaller vertiports might be built at industrial areas, on waterfronts, and above freeways or railyards, where locating a conventional airport would be impossible. (Vertiports can also accommodate helicopters that meet noise standards.) Federal Airport Improvement Program grants could be available for planning and building vertiports. FAA has awarded around $3 million to State and local authorities for civil tiltrotor and vertiport feasibility studies, and the first public heliport designed to vertiport standards is being constructed with some Federal financing at the Dallas Convention Center in Texas.

A tiltrotor network would change local noise patterns, consume more energy, and increase the amount of air traffic relative to comparable service on conventional aircraft. Aircraft noise is a serious problem for airport operators and airlines, and is the leading obstacle to community acceptance of vertiports. On the other hand, knowledgeable engineers claim that less noise will reach the ground from tiltrotors than from conventional airplanes or helicopters. If tiltrotors make inroads into the busiest intercity travel corridors, they will increase substantially the number of daily flights in the air traffic control (ATC) system. For each shuttle jetliner flight replaced, three to five 40-seat tiltrotors would enter the airspace, and appropriate ATC facilities and staffing levels must be ensured, lest tiltrotors overcome runway congestion, but overcrowd segments of the airspace.

Findings and Options

Major findings and options that emerged from this study are as follows:

- **Maglev and tiltrotor concepts are technically feasible.** Prototype U.S. or foreign vehicles have operated for more than a decade. Once installed, these new modes could operate at speeds and intervals that would provide door-to-door trip times competitive with conventional air transport at distances up to 500 miles.

- **Some form of Federal financing will be required if commercial maglev or tiltrotor technologies are to be developed by U.S. industry in the next decade.** The options for Congress to consider range from not funding future work on either tiltrotor or maglev, to very large programs, costing as much as $2 billion or more over a 10-year period. Congress will need to clarify its objectives for supporting these technologies before it can make wise decisions about Federal investment levels.

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[12] Boeing Commercial Airplane Group et al., op. cit., footnote 9.

[13] Ibid., p. i.

- **If improved mobility, new transportation alternatives using U.S. technologies, and international competitiveness are the goals, Federal demonstration and implementation assistance programs must be established.** Federal funding commitments of $800 million to $1 billion are likely to be necessary to develop a full-scale U.S. maglev prototype over the next decade. About $300 million in Federal funds will be required for civil tiltrotor technology development and testing. While these technologies would improve mobility for their users, it is not clear that they would make a measurable impact on traffic congestion levels for the general public.

- **If maintaining technological options for future U.S. maglev and tiltrotor programs is important, Federal R&D funding should be continued at levels of at least $5 million to $10 million annually for each area.**

- **Federal agencies will face additional oversight and regulatory responsibilities—safety, environmental, and economic—that must be supported if maglev, tiltrotor, or other similar systems are placed in service.**

Technical Feasibility

Foreign high-speed rail technology is available now for U.S. markets, and German maglev will be ready by late 1992. The technical feasibility of safely carrying passengers with tiltrotors is not seriously in doubt. Once in operation, maglevs and tiltrotors could avoid airport ground access and runway delays and offer terminals closer to population or industrial centers. If the maglev or tiltrotor vehicles departed as frequently as airliners, they could save time compared with travel by conventional air on particular short- to mid-distance routes.

Federal Financing

Developing tiltrotor or next generation maglev systems to the point of being established and commercially viable would cost billions of dollars. Without Federal management and financial support for infrastructure and precommercial tiltrotor technology development and testing, U.S. industry will not produce either commercial tiltrotors or maglevs in this decade. Public support for infrastructure—rights-of-way for maglev and specific ATC and landing facilities for tiltrotor—will also be necessary, regardless of who advances and sells the technology. OTA assumed that Congress would choose to continue some level of Federal effort for each and has set some guidelines for consideration on that basis. (Table 1-1 shows the steps still necessary for an operational maglev or tiltrotor system.)

Tiltrotor

If Congress decides to continue the V-22 program, enough engineering and operational experience might be gained for industry and investors to make firm decisions, either pro or con, regarding commercial tiltrotor production. R&D that would make tiltrotors and other VTOL aircraft and infrastructure more attractive to communities and airlines could be conducted over the next few years at present funding levels of about $5 million per year.

If a higher priority is given to civil tiltrotor R&D than at present, Federal options range from increasing the percentage of vertical flight research funds devoted to high-speed VTOL concepts to committing funding of $60 million to $90 million per year for developing and testing precommercial tiltrotor technology. The 3-year program suggested in the NASA/FAA report would cost this amount annually, two or three times the amount currently allocated for all NASA and FAA vertical flight programs--and enough to enable U.S. industry to decide on further investment.

Maglev

Unlike the situation with tiltrotor, no established U.S. military technology base exists for maglev development. Consequently, any research program for maglev must be crafted carefully so that a range of components and concepts can be studied at modest expense through the prototype stage. Without a "standard" maglev guideway, technology testing will require separate facilities for each maglev configuration considered; conversely, establishing a standard too early would limit the concepts that could be tested. Significant further investment related to infrastructure needs would be necessary to test and demonstrate

Table 1-1—Steps Still Needed for Operational Maglev or Tiltrotor System

	Commercial tiltrotor	Maglev
Technology development	Military V-22 program engineering and operating experience; noise, flight path, and cockpit research.	Debate revolves around whether to develop new U.S. designs or develop or buy foreign concepts. Low-cost guideways and reliable switches are desirable.
Infrastructure	Conveniently located vertiports; terminal airspace, routes, and procedures; air traffic control (ATC) and navigation facilities.	Available and affortable rights-of-way; dedicated guideways, bridges, grade separations, electrification, communication and control systems, and stations.
Technology and safety demonstration	ATC compatibility; community noise levels; economic data; airline and passenger acceptance.	Construction methods; construction, operating, and maintenance cost data; community and passenger acceptance.
Federal regulatory structure	Mostly exists—specific airworthiness and operating standards for tiltrotors are being developed. Initial vertiport standards have been published.	Not yet developed—some maglev design and performance characteristics conflict with current Federal Railroad Administration (FRA) regulations. FRA is assessing the applicability of current statutes and regulations to the Orlando maglev and developing waivers, guidelines, and possibly new regulations for the project. The Orlando project will be the basis for future maglev regulations.
Legal and environmental concerns	Noise standards; local zoning.	Noise during very high speeds; right-of-way agreements; health effects of electromagnetic fields.
Financing	Under existing policies, Federal support for infrastructure possible but not for aircraft development.	No Federal policy for funding maglev or high-speed rail technology development or infrastructure.
Competitive framework	Airline cooperation is essential for tiltrotors to operate. Individual airlines have well-established operations in highly competitive short-haul markets and see mostly risks and no additional profits in employing tiltrotors. The higher direct operating costs of tiltrotor service might have to be underwritten if tiltrotors are to provide public benefits of expanded airport capacity and reduced delays and congestion.	Airline marketing power and large, established route structure could be strong assets or formidable opponents to intercity maglev. Amtrak has operating authority for most routes proposed for passenger-carrying maglev or high-speed rail.

SOURCE: Office of Technology Assessment, 1991.

vehicle operations under any concept. Federal options range from follow-on funding for the NMI for a few years at levels of about $5 million to $10 million per year, to full-scale development of new maglev technology, which is likely to total more than $750 million.

Additionally, available and affordable rights-of-way and financing for infrastructure are essential to maglev operational feasibility. In fact, a Federal decision for large-scale testing and demonstration might not lead to wide implementation of a U.S. maglev technology without a complementary policy to help establish maglev infrastructure.

Other Decision Factors

Maintaining a broad Federal transportation research base in these and other promising technologies along with extensive data on passenger travel patterns would assist in deciding on and gearing up for a larger scale development effort if conditions warrant it. Increasing concerns over environmental quality and U.S. dependence on foreign petroleum might ultimately require radically different domestic transportation systems, and high-speed, energy efficient maglev has strong potential in this context. Tiltrotors, on the other hand, are heavy energy consumers, and offer less potential than maglevs for surface congestion relief. Both maglevs and tiltrotors would diversify transportation options and might lessen airport ground and air congestion, if passengers can be diverted from conventional air travel.

The most directly related issues are whether (or when) intercity traffic congestion, petroleum consumption, or related environmental concerns will reach unbearable levels, and whether alternative transport modes are viable solutions to these problems. Although dependence on petroleum as an energy source is a recognized issue, there is no consensus on the extent of future congestion, environmental or land-use concerns, nor on the appropriate public policies for addressing these problems. Thus, at present, no clear-cut guidance for choosing among the more costly tiltrotor or maglev options emerges, using these criteria.

Technology Leadership

The national trade benefits and industrial competitiveness implications stemming from commercial development for both maglev and tiltrotor need further study, especially if significant Federal support for a U.S.-produced vehicle or the accelerated development of infrastructure is considered. Currently, the United States has about a 5-year development lead worldwide in tiltrotor technology, and over one-half the potential demand for commercial tiltrotors lies overseas, suggesting a possibly favorable trade position. Maglev is undeniably an exciting new surface transportation alternative, although the world market for U.S.-produced maglev is uncertain. Most locations that could consider investing in maglev systems in the next two decades—Western European countries and Japan—have strong commitments to home-grown technologies. However, regardless of where maglev technology originates, 75 to 90 percent of the expenditures for a maglev system would go to construction and engineering firms that prepare the right-of-way and put the infrastructure—guideways and stations—in place.

Improved Mobility

Each technology, if established, could improve domestic mobility. Congress may wish to give long-term support or encouragement to either or both of these technologies if improved mobility alone is a satisfactory goal. Implementing high-speed rail in selected congested intercity corridors is a near-term way to meet this objective.

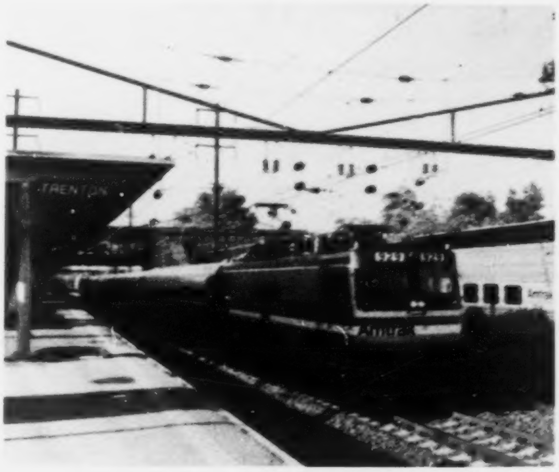

Photo credit: National Railroad Passenger Corp.

The Amtrak Metroliner is the fastest train in North America, reaching speeds of 125 miler per hour.

Neither maglev nor tiltrotor technology has yet been demonstrated as practical for intercity passenger service, and the potential markets for these technologies are difficult to predict with much confidence. The key to commercial success for both tiltrotor and maglev is shifting passengers from other modes, although a very high-speed maglev is likely to attract some additional discretionary travel. Though detailed demand studies are under way, cost and performance projections currently appear insufficient to ensure economic success. Some potential maglev routes, such as Los Angeles to San Diego and Boston to Washington, might eventually be profitable.

Potential entrepreneurs will face significant community and institutional barriers to establishing new transportation systems (see table 1-1 again), and such issues are time consuming and potentially costly to resolve. Moreover, if an intercity maglev, tiltrotor, or high-speed rail system is put into place, their operators will have to compete with the marketing power and pricing flexibility of Amtrak and the large airlines. Tiltrotors would cost more per seat to purchase and operate than conventional airplanes, and maglev routes would need 3 to 5 million passengers per year just to cover a 20-year amortization cost of the guideway at typical air travel fares. Time-sensitive service, such as business travel, is likely to be the initial market for maglev and tiltrotor, if tickets are priced to recover most of the capital and operating costs.

It is not clear from studies to date that either of these new technologies will provide substantial relief for intercity congestion and delays, making them questionable Federal investments solely for that purpose. Moreover, without public willingness to finance infrastructure, neither transportation alternative will be realized.

Federal Responsibilities

Additional research and FAA certification are needed for civil tiltrotor. FAA is well positioned to certify a V-22 for civilian test and demonstration purposes by 1995 if a sponsor requests it and aircraft are available, because it has worked closely with DOD to collect data from the military V-22 flight test program. FAA has low-level programs in place to develop and establish operating regulations, airspace requirements, and technology for advanced vertical flight that could be accelerated if made a priority. Noise standards for tiltrotor have to be finalized to aid in vertiport planning.[14]

The present Federal Railroad Administration (FRA) safety and regulatory framework for conventional railroads cannot be applied directly to maglev or high-speed rail, and FRA's technical and regulatory expertise in these areas needs further bolstering. FRA is working with foreign authorities and developing guidelines for maglev and high-speed rail. However, a separate safety evaluation for different types of technologies, including a total system safety approach for maglev and high-speed rail, is also warranted. FRA's ongoing efforts need expansion and additional support if a thorough system safety program is to be developed. Issues related to the health consequences of electromagnetic fields also require investigation and standard setting. Congress will want to ensure that programmatic support is available to explore these questions, if it decides to pursue implementation of U.S. or foreign technologies.

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[14] Noise standards are established for helicopters (14 CFR 36) and heliport planning (14 CFR 150).

CHAPTER 2

Introduction and Background

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CHAPTER 2
Introduction and Background

Each year more people and goods travel between major cities throughout the world. Fueled by growing and shifting populations, economic development, and changing industry operating practices, this travel demand is straining the capabilities of transportation infrastructure at more and more locations for longer periods of time. Meeting this demand by paving more highways and runways, however, inevitably brings increased petroleum consumption, air pollution, noise, and real estate development, and is heatedly opposed by most communities. Public officials and the transportation industry are taking a close look at new technologies, including magnetically levitated (maglev) vehicles and tiltrotor aircraft, as they consider various investment and management options to address future transport needs.

Maglev vehicles resemble either monorail cars or sleek trains and are lifted and propelled above special guideways by magnetic forces, unlike steel-wheel trains that are mechanically driven along rails. Commercial maglev systems could attain speeds in excess of 300 miles per hour (mph). Several foreign countries have invested substantially in maglev technology development, and low-speed maglevs now regularly carry passengers in transit service in Berlin, Germany, and Birmingham, England.

Tiltrotors, developed and tested by the National Aeronautics and Space Administration (NASA) and the Department of Defense (DOD), can fly like both a helicopter and an airplane. Pivoting engine/rotor assemblies, mounted on each wingtip, permit a tiltrotor to takeoff and land like a helicopter at sites as small as a rooftop when the rotors are vertical, and let it cruise as fast as a propeller-driven commuter airplane when the rotors are tilted forward 90 degrees.

High-speed maglev and military tiltrotor vehicles may be operating regularly in the United States in the next few years. The German Transrapid 250-mph maglev is slated to operate on a 13.5-mile Orlando Airport-to-International Drive route in Orlando, Florida, as early as 1995. The V-22 *Osprey* tiltrotor could be delivered to U.S. Marine Corps squadrons by 1995 if the Federal Government decides to proceed beyond the present full-scale development testing.

Proponents claim that for roughly the same price as an airline ticket, commercial tiltrotors and maglev vehicles could help get travelers to destinations 100 to 500 miles away quicker and more reliably than can existing transportation systems. But even if hundreds of commercial tiltrotors can be sold, tiltrotors will still cost roughly 40 to 45 percent more to build than similarly sized aircraft.[1] And, since 75 to 90 percent of total maglev costs come from the guideway, a maglev route will need millions of riders per year if its capital costs are to be recovered through fares.[2] Thus, each technology will need substantial market demand if it is to provide alternative service at equivalent trip costs to airlines. Understanding future travel patterns is important for assessing the potential of these technologies.

The Federal Government is conducting some modest research and development and operational feasibility studies of maglev and civilian tiltrotor technologies. The Department of Transportation (DOT), the Department of Energy, and the Army Corps of Engineers recently began the National Maglev Initiative to assess the engineering, economic, and environmental aspects of maglev. A major program report, planned for fall 1992, will consider whether to pursue future development of U.S. maglev capability. Additional studies of conventional and high-speed rail systems are under way by the Transportation Research Board, the Federal Railroad Administration, and the Volpe National Transportation Systems Center.

Since 1988, the Federal Aviation Administration (FAA) has awarded grants for 17 tiltrotor airport or

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[1] See ch. 3 for details.
[2] See ch. 4 for details.

"vertiport" planning and feasibility studies, and most should be completed by the end of this year. NASA, DOD, and FAA have jointly funded studies[3] examining civil applications and promising markets for tiltrotor technology. Vertical flight research and technology programs are established at FAA and NASA.

Common Issues for Maglev and Tiltrotor

In DOT's National Transportation Policy, articulated in 1990, the United States is urged to ". . . take full advantage of new and emerging transportation technologies."[4] Maglev and tiltrotor aircraft are identified as options for advancing U.S. transportation technology and expertise and for meeting high-density intercity transportation needs. Although maglev and tiltrotor systems are distinctly different from each other, a number of Federal policy issues and potential markets overlap for these technologies.

Financing

The commercial viability of each transportation mode in the United States—aviation, railroads, motor carriers, marine—has depended heavily on Federal support, primarily for infrastructure or right-of-way. Additionally, the Federal Government has developed (directly and indirectly) various vehicle technologies. A prime example is aviation, where virtually every key commercial technology originated in the military, and where NASA has an explicit mission to investigate technologies with potential commercial application.

Programs such as maglev and tiltrotor development require large cash outlays over long periods while the work is under way, and in some cases, amortization of infrastructure investment takes several decades, far exceeding the patience of private investors. Public financing seems essential if extensive tiltrotor or maglev systems are to be developed in the United States. Moreover, use of public resources, such as some air rights over interstate highways, may also be necessary.

Regulatory Framework

Tiltrotors and maglevs have significantly different design and performance characteristics than conventional aircraft and rail systems, and neither are fully addressed by current Federal safety regulations. Executive branch agencies will have to establish appropriate safety, environmental, and economic oversight responsibilities if maglev, tiltrotor, or other comparable systems are placed in service, and some agencies have this process under way.

Potential Markets and Service Capability

The busiest air travel routes are the primary target markets cited by both maglev and tiltrotor proponents. If terminals can be located close to population and industrial centers, maglevs and tiltrotors might offer quicker point-to-point travel for trips under 500 miles than comparable service via major airports.

Maglevs and tiltrotors might help relieve environmental and congestion problems in other transportation modes. Maglevs are not dependent on petroleum for power, do not degrade air quality where the vehicles operate, and are expected to be more energy efficient than the current and future jetliners with which they would compete in many travel corridors. Tiltrotors could expand the capacity of busy airports by replacing some commuter flights, thereby making runway slots available for larger airliners. Both modes might improve mobility by offering alternatives if ground and air congestion in conventional transportation becomes too severe. However, to reduce overall congestion or energy consumption, favorable market conditions and possibly transportation and energy policies that encourage efficient use of resources might have to be in place to induce enough passengers and operators to switch from conventional modes to maglevs and tiltrotors. Moreover, there is no consensus about the accuracy of transportation congestion and delay forecasts, and about whether and when short-haul transportation alternatives might be warranted or could be effective.

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[3] Boeing Commercial Airplane Co. et al., *Civil Tiltrotor Missions and Applications: A Research Study,* prepared for Federal Aviation Administration, National Aeronautics and Space Administration, and Department of Defense, NASA CR 177452 (Seattle, WA: Boeing Commercial Airplane Co., July 1987); and Boeing Commercial Airplane Group et al., *Civil Tiltrotor Missions and Applications Phase II: The Commercial Passenger Market,* prepared for National Aeronautics and Space Administration and Federal Aviation Administration, NASA CR 177576 (Seattle, WA: Boeing Commercial Airplane Group, February 1991).

[4] U.S. Department of Transportation, *Moving America: New Directions, New Opportunities* (Washington, DC: February 1990), p. vii.

Community Acceptance

Community concerns about transportation noise and land use will be major factors in determining whether tiltrotor or maglev systems can be established. Noise is a problem for transport operators across all modes but is especially serious for airports and airlines, restricting present operations and blocking further growth in some instances. Community groups fighting to curb the noise of airport operations have limited airport development across the country.

If tiltrotors and maglevs are able to provide suitable alternatives to conventional air travel, both technologies could reduce the demand for new airports. Proponents claim that maglev and tiltrotor operations will be quieter in urban areas than conventional trains and aircraft, respectively, but whether such noise levels are acceptable has yet to be determined.

Tiltrotors and maglevs will require new infrastructure. Changes in traffic patterns, aesthetics, and property values that could stem from these facilities and operations will be closely scrutinized by local zoning boards.

International Competition and U.S. Technological Leadership

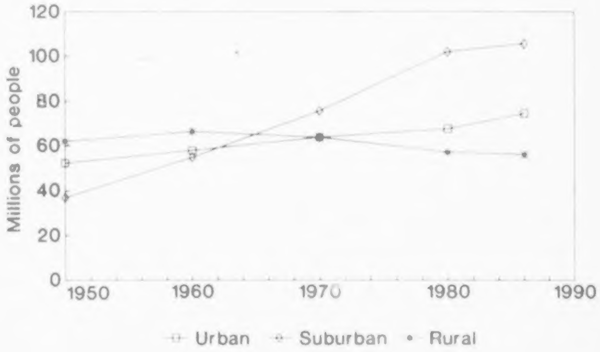
The United States was closely involved in early practical maglev[5] and tiltrotor research but developed only tiltrotor to the point of full-scale testing. U.S. aerospace still maintains a favorable balance of trade, and Europe, the Far East, and developing countries are potential markets for tiltrotors. However, the administration tried, unsuccessfully, to eliminate military tiltrotor funds in fiscal years 1990 and 1991. A Western European consortium is developing commercial tiltrotor technology and a Japanese company plans to produce a similar vertical flight vehicle based on tiltwing technology. Some contend that if the military V-22 program is terminated, foreign-produced aircraft could win control of any potential U.S. (and world) advanced vertical flight market.[6]

Federal funding for maglev ended in the United States in 1975. A decade later, German and Japanese companies were marketing maglev technologies in this country.

Intercity Passenger Travel in the United States

The migration of people from rural locations and inner cities (see figure 2-1) to suburbs has drastically altered traffic patterns and volumes in metropolitan areas.[7] Business activity has become more decentralized as employers followed workers.[8] Automobile use, virtually required for living or working in the suburbs, has grown steadily, regularly passing expected levels (see figure 2-2). For the intercity commercial traveler, these trends have resulted in longer and more congested trips to get to an airport or rail terminal. During the past decade, airline deregulation spurred rapid growth in passenger travel and encouraged air carriers to concentrate flights at hub airports, leading to considerable delays when using the busiest airports.

Figure 2-1—Population Trends in the United States



SOURCE: Office of Technology Assessment, based on U.S. Bureau of the Census data, 1991.

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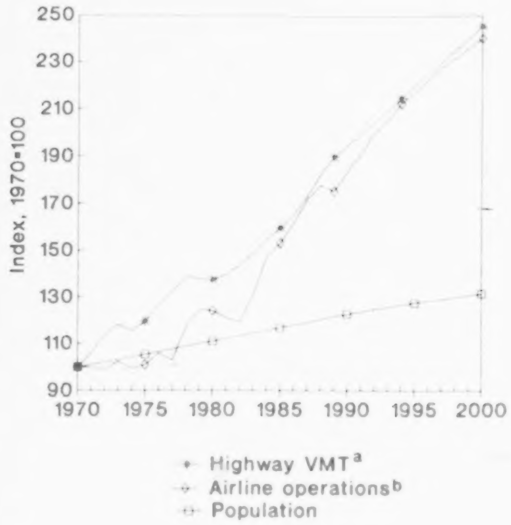
[5] Seminal magnetic levitation research (for electromagnetic suspension) began in Germany in 1922.

[6] Federal Aviation Administration, Research, Engineering, and Development Advisory Committee, Tiltrotor Technology Subcommittee, *Report* (Washington, DC: June 26, 1990), p. 15.

[7] U.S. Department of Transportation, *National Transportation Strategic Planning Study* (Washington, DC: U.S. Government Printing Office, March 1990), p. 5-1.

[8] Ibid., p. 5-10.

Figure 2-2—Forecast and Trends in Population, Automobile Use, and Airline Operations



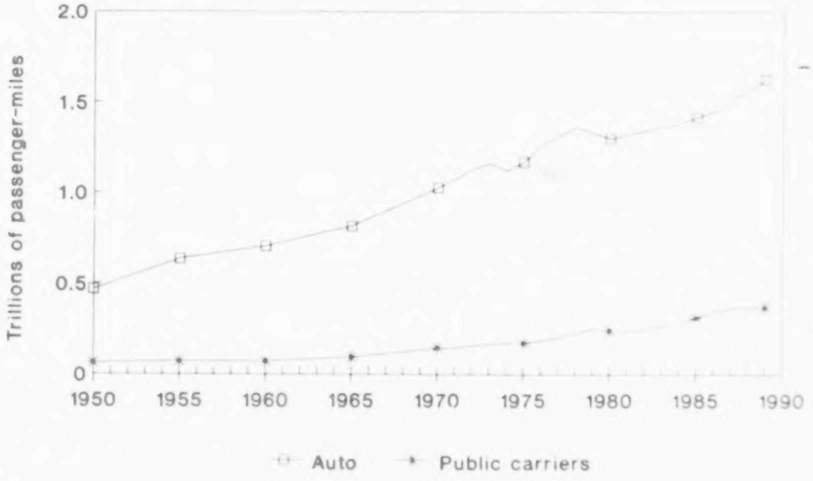
[a] VMT = vehicle-miles traveled. [b] Takeoffs and landings.

SOURCE: Office of Technology Assessment, 1991, based on information from the Federal Highway Administration, the Federal Aviation Administration, and the U.S. Bureau of the Census.

In the United States, the automobile has been the mode of choice for domestic intercity travel since the 1930s (see figure 2-3), although commercial aviation passenger travel grew at a faster rate until the past few years (see figure 2-4). The growth of both modes was encouraged by public policies and funding. Trips by automobile can be significantly cheaper, especially for group travel, and more convenient than by other modes. For distances under 100 miles, cars generally provide the quickest way of getting from door to door. However, as trip distance increases, travel time by auto falls further and further behind rail and air modes. People for whom trip time is the deciding factor, such as business travelers, depend heavily on airlines for intercity trips.

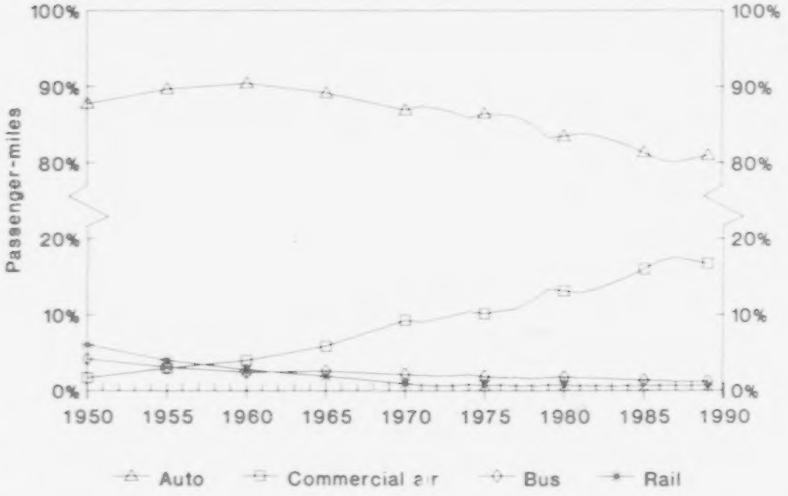
Airlines carry most commercial intercity passengers, although rail service is significant in the Northeast and California. Air travel began to dominate the common carrier market in the mid-1960s, and has steadily increased its share despite the creation of Amtrak in the 1970s. These trends suggest that any new high-speed transport system will have to focus, initially at least, on strong air travel markets. However, the volume of highway traffic to draw on is so large that if a tiny fraction of automobile users were to switch to maglev or tiltrotor, it would be significant for the

Figure 2-3—U.S. Intercity Passenger Travel by Public Carriers and Private Automobile



SOURCE: Office of Technology Assessment, 1991, based on data in Eno Foundation for Transportation, *Transportation in America* (Washington, DC: 1990).

Figure 2-4—U.S. Intercity Passenger Travel by Modal Share



SOURCE: Office of Technology Assessment, 1991, based on data in Eno Foundation for Transportation, *Transportation in America* (Washington, DC: 1990).

ridership of these new modes. Moreover, the first two high-speed maglev routes proposed for the United States are primarily automobile markets.[9]

Intercity Travel Markets

Population and distance strongly influence the volume of passengers traveling between two areas. In general, passenger traffic increases as population grows, and, other things being equal, travel between two cities will be greater the closer they are.[10] The busiest travel corridors are centered on the largest cities, but cultural, political, industrial, and geographical factors also affect intercity travel.

What constitutes an intercity travel market, or city pair, depends on how travel origins and destinations are defined. One way to define each end of a city pair is to use the Department of Commerce's metropolitan statistical areas—closely linked urbanized regions that extend across jurisdictional boundaries. A key characteristic of a market suitable for maglev or high-speed rail may be the potential for connecting the city pair with a single guideway (with branches or closely spaced stops in the metropolitan areas). For example, both the Los Angeles basin and the San Francisco Bay area cover a large region and are served by multiple airports, but theoretically only one double-track guideway would be necessary for the 250 miles or so between the outskirts of these broad locales. Guideways, of course, are not a factor for tiltrotor, and these market boundaries are not precisely applicable to tiltrotor market analyses. Commercial tiltrotor operators might serve routes with too few passengers for rail or maglev, since tiltrotors have relatively modest ground infrastructure requirements.

The largest travel corridors in the United States with trip distances suitable for maglev or tiltrotor are along the east and west coasts. DOT statistics on origin-to-destination airline travel indicate that the busiest corridor lies between San Francisco and Los

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[9] The two routes are Orlando Airport to International Drive in Orlando, FL, and Anaheim, CA to Las Vegas, NV.

[10] To estimate traffic volumes, transportation planners sometimes use the gravity model, so named because it is similar to the formula for calculating the gravitational force between two objects.

Table 2-1—Domestic U.S. Air Travel for 1988 Between Major Urban Areas Separated by Less Than 600 Miles

City pair		One-way passenger trips (millions)	Distance between city pairs (miles)
Los Angeles	San Francisco	6.6	347
New York	Boston	3.4	191
New York	Washington	3.3	214
Los Angeles	Phoenix	2.6	348
Dallas	Houston	2.0	222
San Diego	San Francisco	1.8	447
Los Angeles	Las Vegas	1.6	221
Chicago	Detroit	1.4	238
Las Vegas	San Francisco	1.3	408
Los Angeles	Sacramento	1.1	383
Boston	Washington	1.1	400
Chicago	Minneapolis	1.0	344
Detroit	New York	0.9	489
Chicago	St. Louis	0.9	256
Buffalo	New York	0.9	293
Phoenix	San Diego	0.8	304
Dallas	San Antonio	0.8	253
New York	Pittsburgh	0.8	329
Chicago	Washington	0.8	596
Dallas	Austin	0.7	187
Las Vegas	Phoenix	0.7	255

SOURCE: Volpe National Transportation Systems Center, 1991.

Angeles,[11] with the Northeast Corridor city pairs of New York-Boston and Washington-New York in second and third places, respectively (see table 2-1). When travel only between specific airports is examined, Boston Logan-New York LaGuardia and Washington National-LaGuardia are the leading routes. If the trend of migration to the Sunbelt continues, one DOT report estimates that by the year 2000 the only eastern or midwestern city pairs in the top 10 markets will be Washington-New York and Boston-New York, and they will be third and fourth, respectively (see table 2-2). However, when highway traffic is included, the Northeast Corridor is more traveled than anywhere in Europe or North America.

Many factors in potential markets will have to be examined closely to determine if maglev or tiltrotor service is feasible. How many terminals are needed and where to locate them in a metropolitan area are aspects critical to the total trip-time advantage of these technologies. Additionally, local opposition to new infrastructure development and transportation operations may put some markets out of reach.

Table 2-2—Projected U.S. Domestic Air Travel for Year 2000 Between Major Urban Areas Separated by Less Than 600 Miles

City pair		One-way passenger trips (millions)	Distance between city pairs (miles)
Los Angeles	San Francisco	12.8	347
Los Angeles	Phoenix	6.5	348
New York	Washington	5.2	214
New York	Boston	4.7	191
Dallas	Houston	4.5	222
Los Angeles	Las Vegas	4.1	221
San Diego	San Francisco	3.7	447
Las Vegas	San Francisco	3.1	408
Los Angeles	Sacramento	2.6	383
Phoenix	San Diego	2.3	304
Las Vegas	Phoenix	2.0	255
Dallas	San Antonio	2.0	253
Dallas	Austin	1.9	187
Chicago	Detroit	1.8	238
Boston	Washington	1.7	400
Chicago	Minneapolis	1.5	344
Detroit	New York	1.2	489

SOURCE: Volpe National Transportation Systems Center, 1991.

Passenger Travel Data

Public data on passenger transportation in the United States is sparse (see box 2-A). Commercial carriers gauge intercity passenger volumes from ticket receipts, and the major airlines, with reporting requirements stemming from the days of the Civil Aeronautics Board, provide what public detail there is on air passenger travel. Automobile travel statistics, when compiled, usually focus on local transportation or are based on gross assumptions. For example, passenger-miles traveled by automobile in the United States are calculated from Federal fuel tax revenues. For common carriers and automobiles alike, only city-to-city or terminal-to-terminal passenger travel estimates can be made—precise origin-to-destination patterns are not well understood. **All together, passenger data are sufficient for identifying the largest transportation markets and for estimating traffic volumes, but a better picture of how people travel door-to-door and how factors other than price affect travel demand is necessary for predicting with much certainty the ridership potential of new high-speed transportation systems.** In support of the National Maglev Initiative and FAA civil tiltrotor studies, DOT's Volpe National Trans-

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[11] This corridor includes four airports in the Los Angeles metropolitan area (Los Angeles, Burbank, Orange County, and Ontario) and three airports in the Bay Area (San Francisco, Oakland, and San Jose).

Box 2-A—Passenger Travel Databases

Public data on intercity passenger travel are limited primarily to statistics reported by commercial carriers and to occasional surveys of automobile users. This information is sufficient for identifying the largest intercity travel corridors but provides little insight into the specific trip origins and destinations and passenger decision factors that will be critical in planning maglev or tiltrotor routes. Door-to-door travel time and cost are important factors in passenger choice of transportation modes, and little public data exist on total trip times and expenses.[1] The Federal Railroad Administration (FRA) found that intercity rail and air passenger data were adequate for analyzing a possible high-speed rail system but that highway data were deficient.[2] Moreover, data on transportation congestion and delays, crucial factors for maglev and tiltrotor viability, are generally crude.

Airline passenger statistics, a legacy of the era when U.S. airlines were closely regulated, are superior to those of other modes. In 1985, the Department of Transportation (DOT) assumed the former Civil Aeronautics Board's responsibility for collecting data on airline operations, traffic, and finances, and the primary source of airline passenger data is the Uniformed System of Accounts and Reports for Large Certificated Air Carriers.[3] Large airlines, those that operate aircraft with more than 60 seats, are obligated to report operating, financial, and passenger data by airport and aircraft type and in total. Since these reports do not identify specific passenger travel patterns, DOT requires certain air carriers to collect a statistically valid sample of passenger tickets for each route and to report trip origins and destinations, connecting or stopover points, and the dollar value of each ticket.[4] Demographic information, which often underscores changes in travel patterns, is not contained in these reports. Travel agents and airlines with extensive computer reservation systems keep more detailed, but proprietary, databases of passenger characteristics important for market forecasting.

Because Amtrak and Greyhound bus lines have a virtual monopoly on intercity passenger rail and bus transport, respectively, ticket information available in the companies' annual reports gives some indication of traffic volume. The Nationwide Personal Transportation Study (NPTS) administered by the Federal Highway Administration (FHWA) gives information on daily household travel patterns, offering some insight on demographic and household trends. However, because trips over 100 miles account for only 0.7 percent of all trips, the NPTS is of little value in determining intercity volume.[5] Another drawback is the infrequency of the study. A 12-month study recently begun in 1990 is the first one conducted in 7 years.

The U.S. Travel Data Center, a private organization, also surveys Americans on their travel patterns. Each month the center conducts a National Travel Survey (NTS) of 1,500 adults, collecting data on trips longer than 100 miles taken during the previous month. The NTS is primarily a data source for the travel industry, but DOT has used NTS results in compiling intercity trip information.

Unlike public carriers, automobile use does not entail a ticket purchase. Consequently, gathering highway passenger data is problematic. Local transportation authorities usually understand commuting patterns in their own communities, but a nationwide picture of automobile travel is lacking.

There are two major sources of highway data managed by FHWA: the Highway Performance Monitoring System (HPMS) and the NPTS, neither of which is very helpful in determining intercity travel patterns. States report to HPMS on pavement condition, miles, and use for a sample of 102,000 miles of collector and arterial

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[1] John P. O'Donnell, Volpe National Transportation Systems Center, personal communication, June 28, 1991.

[2] Because of government operation of Amtrak, passenger rail data are much easier to obtain. Arthur B. Sosslau, "Surface Transportation Data Needs, Resources, and Issues," *Transportation Research Record*, No. 1253, January 1990, p. 43.

[3] 14 CFR 241.

[4] At least 1 percent of the total tickets for large domestic markets and 10 percent for other markets are included in each sample.

[5] Sosslau, op. cit., footnote 2, p. 44.

Continued on next page

Box 2-A, continued

roadways. Although these statistics include vehicle-miles traveled, HPMS data provide little information on intercity travel since they contain no origin-destination data.

Transportation congestion and delays are difficult to quantify reliably and consistently. For example, FHWA has yet to develop a surface congestion measurement system. Local authorities can usually monitor road congestion, but the information is often not incorporated at the Federal level where it can be used on a nationwide basis. And even if the data were included in Federal studies, lack of coordination between agencies that gather information makes a complete picture of travel patterns difficult.[6]

DOT maintains three aviation delay reporting systems. Air traffic controllers record the number of flights delayed by 15 minutes or more and the cause of the delay. Separate delaying events, such as waiting for takeoff clearance or rerouting because of weather, go unreported if each event results in delays of less than 15 minutes, although the total delay for the flight might exceed 15 minutes.

The Federal Aviation Administration also collects data directly from certain airlines on all delays, regardless of length, and the phase of flight in which they occur. This Standardized Delay Reporting System (SDRS) once accounted for 25 percent of all air carrier flights. Due to industry financial difficulties, only one airline currently provides data to SDRS.[7] The third database, DOT's widely publicized compilation of airline on-time performance, indicates how well airline schedules anticipate delays.

To address data concerns, the DOT budget for fiscal year 1993 calls for the resumption of the NTS (different from the one conducted by the U.S. Travel Data Center), which was abandoned in 1977. This multimodal survey would help determine regional travel patterns more completely. The actual details of what would be included in the survey have yet to be ironed out.

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[6] U.S. Congress, Office of Technology Assessment, *Delivering the Goods: Public Works Technologies, Management, and Financing*, OTA-SET-477 (Washington, DC: U.S. Government Printing Office, April 1991), p. 11.

[7] James McMahon, Office of System Capacity and Requirements, Federal Aviation Administration, personal communication, May 23, 1991.

portation Systems Center is examining various local travel surveys and will try to project intercity travel by zones representing different parts of metropolitan areas.[12] Furthermore, high-speed rail planners have improved their methods for estimating ridership in recent high-speed rail system proposals.[13]

Air travel data offer less information on commercial travel potential between cities less than 150 miles apart, because conventional aircraft offer little time savings, if any, over surface modes on these routes. However, some of these markets, such as Houston-Austin, Los Angeles-San Diego, Phoenix-Tucson, and Portland-Seattle, have greater air travel than would be expected, and might be feasible for maglev or tiltrotor service.[14]

Transportation Forecasts

The consensus among transportation forecasters is that intercity travel, and the demand for roads and airports, will continue to grow well into the next century. Population growth, economic strength, and past traffic patterns are the primary factors for travel forecast models. Population data and forecasts are detailed and generally reliable, but information on passenger travel by automobile, and measurements of highway and air traffic congestion, are crude.

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[12] Arrigo P. Mongini, deputy associate administrator for Passenger and Freight Services, Federal Railroad Administration, personal communication, July 1, 1991.

[13] Joseph Vranich, High Speed Rail Association, personal communication, June 27, 1991.

[14] John B. Hopkins, "Overview of Intercity Passenger Travel," *Passenger Transportation in High-Density Corridors* (Cambridge, MA: U.S. Department of Transportation, Volpe National Transportation Systems Center, November 1990), p. 4

The most prominent population trends include the shift from the Northeast and Midwest to the Sunbelt, the continuing migration to the Nation's metropolitan areas and the decentralization of these same cities, and the increasing number of households. A combination of economic and demographic factors have contributed to the steady increase in automobile traffic. In the 1960s, traffic trends directly reflected population growth. However, traffic continued to increase steadily, even though the U.S. population growth rate decreased during the past 20 years. The number of households and workers increased about one-third faster than the total population during this period, helping spur this demand for automobile travel.[15]

According to Texas Transportation Institute data, the past decade has already seen a significant increase in road congestion in major metropolitan areas (see table 2-3). Nationally, average urban congestion increased by 16 percent between 1982 and 1989, and congestion in cities such as Los Angeles, Washington, DC, San Francisco, and San Diego grew two or three times this rate during the same period. Congestion data on highways between cities are not as readily available.

Table 2-3—Roadway Congestion Changes in Major Urban Areas, 1982-89[a]

City	Percent change
San Diego	51
San Francisco-Oakland	35
Washington	27
Seattle-Everett	27
Los Angeles	26
Sacramento	26
Austin	25
Portland	23
Orlando	22
Dallas	21
Boston	21
San Antonio	21
Miami	19
Chicago	19
Baltimore	18
San Bernardino-Riverside	16
Fort Worth	14
San Jose	14
New York	11
Tampa	10
Pittsburgh	5
Philadelphia	5
Houston	–2
Detroit	–4
Phoenix	–10

[a] Congestion level is based on the Roadway Congestion Index (RCI) developed by the Texas Transportation Institute. The RCI calculates roadway mobility by combining average traffic volume per lane-mile for freeways and principal arterial streets, accounting for total vehicle-miles traveled and the capacity of each type of road.

SOURCE: Office of Technology Assessment, based on Texas Transportation Institute, "1989 Roadway Congestion," *Research Report* 1131-4, 1991.

FAA figures indicate that both the number of airline flights and the average time delayed per flight increased by about one-third during the past decade.[16] However, most of this growth was prior to 1987. Nevertheless, FAA predicts that the number of congested airports will nearly double, to 41, by 1998.[17]

Events such as energy crises or even macroeconomic cycles that are difficult to predict make forecasting the demand for new transportation projects and infrastructure precarious. Environmental, demographic, and cultural changes and transportation industry strategies will also affect future travel, but are difficult to quantify and predict using mathematical models. For instance, policymakers lost interest in Federal High Speed Ground Transportation Act programs over a decade ago, when the dire predictions of gridlock on the highways and airways of the Northeast Corridor failed to materialize. However, surface and air traffic did continue to grow, and public and private entities took steps to increase highway, aviation, and rail capacity.

The extent of future intercity traffic jams is difficult to assess because congestion forecasts are based on inadequate databases (see box 2-A again) and the implicit assumption that automobile drivers and airlines will continue to try to squeeze more vehicles into saturated locations. Airline strategies rather than passenger demand sometimes govern congestion, especially at hub airports. For example, at the four airports expected to be the most severely congested by the turn of the century—Chicago O'Hare, Dallas-Fort Worth, Atlanta, and Denver—the majority of passengers fly in just to change planes for another destination.[18] Changes in operating practices and vehicle occupancy rates in the air and on the ground could dramatically alter congestion levels. Additionally, changes in energy or environmental costs to vehicle operators and advances in telecommunication technologies could alter the demand for transportation.

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[15] U.S. Department of Transportation, op. cit., footnote 7, pp. 1-7 and 5-8.

[16] According to the Federal Aviation Administration's Standardized Delay Reporting System database, airline delays averaged 11.8 minutes per flight in 1980 and 15.6 minutes per flight in 1988.

[17] U.S. Department of Transportation, Federal Aviation Administration, *1990-91 Aviation System Capacity Plan*, DOT/FAA/SC-90-1 (Washington, DC: September 1990), p. 1-13.

National leadership is a crucial ingredient for efficient transportation, but local communities often establish land-use and development policies that lead directly to metropolitan gridlock. Local citizens and the airline industry have a strong say in airport development and have, for the most part, delayed or squelched airport expansion in urban areas. The only new major airport (the replacement for Denver Stapleton) now being built in the United States was opposed by the dominant hub airlines at Denver. Due in part to the reluctance of these airlines, the initial plans for the airport have been scaled back, and recent forecasts for passenger travel through the airport have fallen significantly from projections made in the mid-1980s.[19] Generally, there are fewer congestion problems on the intercity portions of the transportation infrastructure, such as airways and highways, than on local segments.

Passenger Travel Patterns in Other Countries

Public policies have created entirely different travel conditions overseas, and the largest commercial intercity transportation markets in the world are in Western Europe and Japan, regions with higher population densities and more closely spaced cities relative to the United States. Each of the countries depends strongly on conventional and high-speed rail for medium length trips, and some are developing or planning to develop maglev vehicles and tiltrotor-type aircraft. However, since public policies, economies, and social structures differ markedly overseas, transportation comparisons with the United States, including the market potential of maglev and tiltrotor systems, must be viewed with caution.

Key Differences Between U.S. and Foreign Markets

Japan and the countries in Western Europe have population densities from 4 to 13 times that of the United States (see figure 2-5) and more of their people live in urban areas. However, certain regions of the United States are densely populated. For example, the population density in the Northeast Corridor between Massachusetts and Washington, DC, is slightly higher than that of central Europe.

With low automobile and energy prices in effect since the 1920s and a widely spread populace, the United States focused its transportation policies, relative to those of other countries, more on aviation and private automobiles than on surface transit. The level of auto ownership attained by United States in the 1930s was not reached by war-torn Western Europe and Japan until the late 1960s and early 1980s, respectively (see figure 2-6). Consequently, these areas had to address mass transit modes such as rail. Now, the private automobile dominates local and intercity travel in every developed country.[20]

The major difference between travel in the United States and its overseas counterparts is in the role of public carrier modes. Geographic and political factors, such as having dominant transportation corridors, encouraged passenger rail development in Europe and Japan. For example, the Japanese corridor of Tokyo-Nagoya-Osaka contains one-half of Japan's people but only 10 percent of Japan's land area. Similar situations exist in European countries, with the capital cities of London and Paris dominating British and French lives, respectively. In the United States, no single region has the political strength to garner the lion's share of Federal transportation funds. In Europe and Japan, trains carry the majority of commercial passengers, whereas in the United States, almost all common carrier travel is by air. However, airlines have been increasing their market share in Europe and may continue to gain if bureaucratic barriers and prices fall as Europe deregulates its air carrier industries during the next decade.

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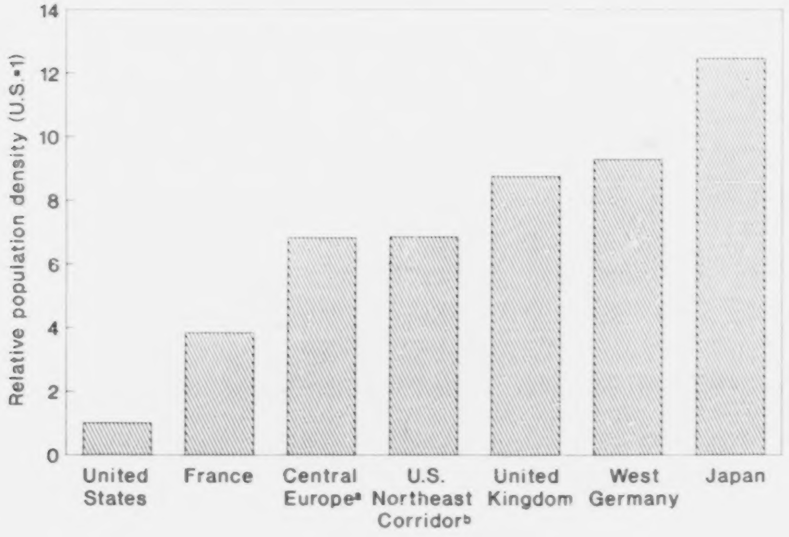
[18] U.S. Congress, Office of Technology Assessment, *Safe Skies for Tomorrow: Aviation Safety in a Competitive Environment,* OTA-SET-381 (Washington, DC: U.S. Government Printing Office, July 1988), p. 33.

[19] John P. O'Donnell, Volpe National Transportation Systems Center, personal communication, June 28, 1991.

[20] U.S. Department of Transportation, op. cit., footnote 7, p. 6-7.

Figure 2-5—Population Density of Selected Countries



[a] West Germany, Italy, United Kingdom, France, the Netherlands, Belgium, and Switzerland.

[b] Massachusetts, Connecticut, Rhode Island, New Jersey, Delaware, Maryland, District of Columbia, one-half of Pennsylvania, and one-half of New York.

SOURCE: Office of Technology Assessment, 1991, based on data from Volpe National Transportation Systems Center, and Population Reference Bureau, World Population Data Sheet (Washington, DC: 1989).

Moreover, other countries find it much easier to cross-subsidize transportation operations. Because many foreign rail operations, and some air service, are traditionally government-owned monopolies, or near-monopolies, financial assistance for transportation industries is an expected part of national spending.[21] Automobile fuel taxes amounting to $3 per gallon in some countries (see figure 2-7) help raise general revenues and support the more energy-efficient and environmentally sound public transit systems. Most European countries reinvest into roads about one out of every three dollars they receive in highway fees and taxes. The comparable U.S. spending ratio is about one-to-one, but U.S. taxes and transportation-related fees are much lower than in Europe, so the U.S. total is less. In other parts of the world, such as Argentina and Australia, governments draw considerably on general revenues to finance highways.[22]

Although the infrastructure for each transportation mode in the United States was initially provided with public funds, new Federal financial support for transportation facilities that is not backed by user fee revenues draws fire from competing interests. Urban Mass Transit Administration grants for mass transit are supported by a 1.5-cent-per-gallon tax on gasoline, but in general, transportation trust fund dollars do not cross modal boundaries. Proposals to allow flexible and cross-modal use of highway funds by States have been introduced in recent surface transportation legislation in Congress.

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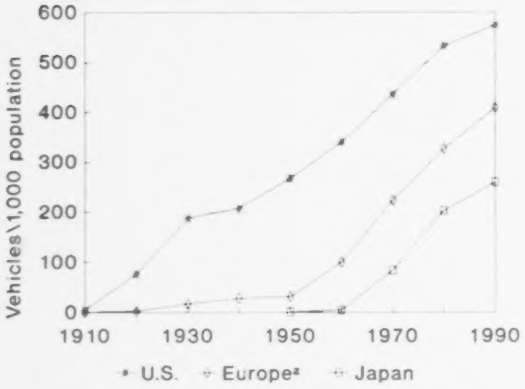
[21] The Tokaido Shinkansen high-speed train in Japan and the TGV Paris-Lyon high-speed train in France are reportedly self-supporting.

[22] U.S. Department of Transportation, op. cit., footnote 7, p. 6-10.

Figure 2-6—Private Passenger Vehicles per 1,000 Population, 1910-90

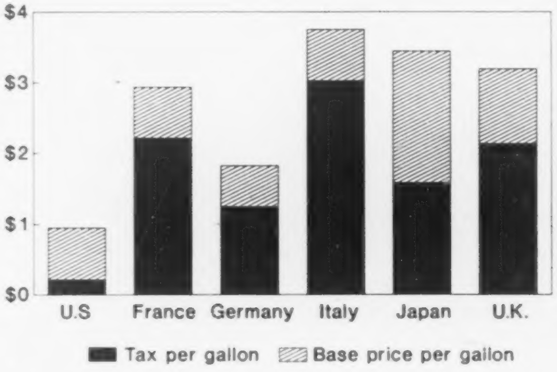


[a]Average for France, Germany, and the United Kingdom.

NOTE: 1990 values as estimated from 1987 data.

SOURCE: Volpe National Transportation Systems Center, 1990.

Figure 2-7—Gasoline Prices in Selected Countries[a]



[a]1988 dollars.

SOURCE: Office of Technology Assessment, 1991, based on data in Editors of the Economist, *The Economist Book of Vital World Statistics* (London, England: The Economist Books, Ltd., 1990).

CHAPTER 3

Tiltrotor System Issues

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CHAPTER 3
Tiltrotor System Issues

A major irony of the jet age is that most of the time spent in airline travel is on the ground. For airline trips under 700 miles or so, passengers spend over one-half their total journey's time on the roads surrounding airports, at the terminal, and in the aircraft while it taxis and waits for takeoff clearance or an available gate after landing.[1] Ever since helicopters entered civilian service soon after World War II, transportation planners have envisioned intercity air travel virtually from doorstep to doorstep. Proponents claim that tiltrotor aircraft, which can fly like both helicopters and airplanes, hold the promise of such service at trip costs comparable to fixed-wing aircraft flights and offer options to increase the capacity of congested airports. However, there are enough concerns about community acceptance, adequate infrastructure, and market demand that private industry is not yet willing to risk investment capital to develop commercial tiltrotor aircraft.

The helicopter is the most familiar aircraft design with vertical takeoff and landing (VTOL) capabilities but has never been widely used for scheduled intercity transportation. Fundamental speed and payload limitations put helicopters at a distinct economic disadvantage to comparable commuter turboprop aircraft, whose operating costs are three to five times lower.[2] However, many other VTOL concepts, including some with the performance potential of conventional airplanes, have been examined during the past four decades.[3] The National Aeronautics and Space Administration (NASA) and the U.S. military are developing one such VTOL vehicle, a tiltrotor called the V-22 *Osprey*,[4] which has pivoting engine/rotor assemblies mounted on each wingtip. The aircraft operates like a helicopter when the rotors are in the vertical position, but when the rotors are tilted forward 90 degrees, the tiltrotor flies like an airplane. Tiltrotors and similar "powered-lift" vehicles bridge the speed and range gaps between helicopters and airplanes.[5] Possible applications for tiltrotors include helicopter missions where increased speed and range are important, such as search-and-rescue missions, and conventional fixed-wing flights where avoiding air and ground congestion, delays, or restrictions is particularly valuable. However, the focus of this study is on tiltrotor use for scheduled intercity travel only.

The V-22 *Osprey*, currently under full-scale development for a variety of military missions, is the technology base for a U.S. civil tiltrotor. Five V-22 aircraft are to be used in the flight test program. As of June

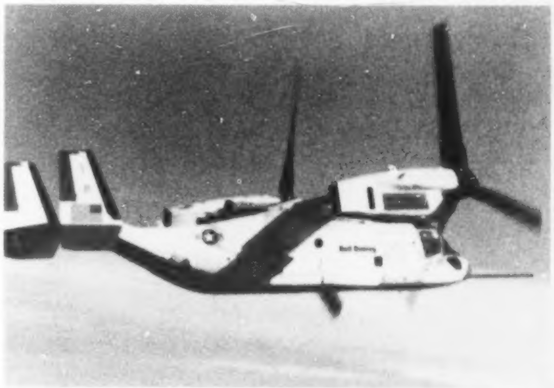

Photo credit: Bell Helicopter Textron, Inc.

Designed for a variety of military missions, the V-22 *Osprey* tiltrotor is now in full-scale development.

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[1] Bell Helicopter Textron, "Tiltrotor: A National Transportation Asset," promotional booklet, n.d.

[2] David Lawrence, "Helicopters and Today's Air Transportation System," *Transportation Quarterly*, vol. 45, No. 2, April 1991, p. 164.

[3] However, the only vertical takeoff and landing designs that have gone into production are helicopters and vectored-thrust military jets.

[4] The National Aeronautics and Space Administration developed a tiltrotor research aircraft known as the XV-15 in the 1970s. The current Department of Defense tiltrotor program is for a larger, multipurpose tiltrotor, the V-22 *Osprey*.

[5] The Federal Aviation Administration certification standards cover three broad classes of aircraft: airplanes, rotorcraft, and manned balloons. Powered-lift aircraft establish a new category since they can fly at high speeds like airplanes and go slow, possibly hover, and takeoff and land vertically (or near vertically). These vehicles use jet or rotor thrust for lift, control, and propulsion—hence the term "powered-lift." Airplanes create lift primarily from the airflow over the wings that results from vehicle movement; thrust is fore and aft only, and contributes little to control and lift.

1991 these aircraft have accumulated more than 550 flight hours.[6] U.S. manufacturers could develop and produce a market-responsive[7] tiltrotor by the end of this decade if favorable travel demand estimates are established and supportive national transportation policies are put in place.

The Department of Transportation and NASA are conducting modest tiltrotor research and development (R&D) and operational feasibility and market assessment studies. Since 1988, the Federal Aviation Administration (FAA) has awarded grants for 17 vertiport planning and feasibility studies, most of which should be completed by the end of 1991. FAA, NASA, and the Department of Defense (DOD) have jointly funded studies[8] examining civil applications and promising markets for tiltrotor technology, and the latest study concludes that civil tiltrotors could be competitive with fixed-wing aircraft in certain markets, provided adequate air and ground infrastructure is in place and tiltrotor operations prove to be acceptable to communities, air carriers, and the traveling public (see box 3-A).[9]

Tiltrotor technology may have implications for national competitiveness in aviation industrial base strength, international technology leadership, balance of trade, and domestic transportation productivity. Currently, the United States has more than a 5-year development lead worldwide in tiltrotor technology.[10] Over one-half the potential demand for commercial tiltrotors lies overseas.[11] OTA has recently completed, or has under way, studies on international trade and industrial policies, including aviation industry issues regarding Japan and Western Europe.[12]

There is also foreign interest in developing high-speed VTOL aircraft and in producing commercial products. Eurofar, a European consortium of five helicopter manufacturers, has plans to develop a commercial tiltrotor prototype over the next 5 years, with support from their governments. Japan is hoping vertical flight will overcome some of its severe transportation constraints. A Japanese organization has announced plans to construct a network of over 3,000 heliports across the country by 2020.[13] After viewing a V-22 flight demonstration at Bell Helicopter's Fort Worth plant, Japan's Minister of International Trade and Industry reportedly said, "If you build it, we will buy it. If we can't buy it from you, we will build it."[14] Japan's Ishida Group is financing the development of a 14-passenger tiltwing for corporate and business markets.

Tiltrotor System Concepts

As a basis for discussion of commercial tiltrotor technology and its potential for intercity transportation, this section describes a generic, commercial passenger tiltrotor system. The description is not meant to imply that the concept is practical or recommended. Tiltrotor applications other than common carrier service are not considered.

Congestion Is the Key

Transportation limitations within our busiest intercity corridors make tiltrotor service potentially attractive. Traffic delays on the roads and airways surrounding airports lengthen an air traveler's journey, and coping with future aviation traffic growth will entail changes in highway systems as well as airport

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[6] Stanley W. Kandebo, "Osprey Flight Tests Suspended After Crash of No. 5 Aircraft," *Aviation Week & Space Technology*, vol. 134, No. 24, June 17, 1991, p. 54.

[7] The V-22 design is not considered suitable for most commercial applications (see later sections).

[8] Boeing Commercial Airplane Co. et al., *Civil Tiltrotor Missions and Applications: A Research Study*, prepared for Federal Aviation Administration, National Aeronautics and Space Administration, and Department of Defense, NASA CR 177452 (Seattle, WA: Boeing Commercial Airplane Co., July 1987); and Boeing Commercial Airplane Group et al., *Civil Tiltrotor Missions and Applications Phase II: The Commercial Passenger Market*, prepared for National Aeronautics and Space Administration and Federal Aviation Administration, NASA CR 177576 (Seattle, WA: Boeing Commercial Airplane Group, February 1991).

[9] Boeing Commercial Airplane Group et al., Phase II Draft Final Report, op. cit., footnote 8, p. 1-3.

[10] Philip C. Norwine, vice president, Commercial Market Development, Bell Helicopter Textron, personal communication, July 18, 1991.

[11] Boeing Commercial Airplane Group et al., Phase II Summary, op. cit., footnote 8, p. 23.

[12] U.S. Congress, Office of Technology Assessment, *Competing Economies: America, Europe, and the Pacific Rim* (Washington, DC: U.S. Government Printing Office, in press).

[13] Japan Heli Network Co., Ltd., promotional materials for Helicopter Association International Heli-Expo 90, Feb. 4-6, 1990, Dallas, TX.

[14] Frank J. Gaffney, Jr., director of the Center for Security Policy, testimony at hearings before the House Committee on Public Works and Transportation, Subcommittee on Aviation, Apr. 25, 1990.

Box 3-A—Federally Funded Civil Tiltrotor Studies

The Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration (NASA) began to consider civil applications of tiltrotors seriously during the early 1980s, after the military decided to develop tiltrotor technology for a new multiservice, multimission vertical takeoff and landing (VTOL) aircraft. In 1985 FAA proposed a joint civil tiltrotor study with NASA and the Department of Defense (DOD) to "... assess the broader implications of the V-22 aircraft development to the nation as a whole. This includes the potential for other versions and sizes, both civil and military, civil certification issues, civil production impact on the defense industrial base and any indirect technology spinoffs. . . ."[1] NASA, DOD, and FAA awarded a $1-million study contract to Boeing Commercial Airplane Co., teamed with Bell Helicopter Textron Inc., and Boeing Helicopters to investigate potential commercial, corporate, and public service markets, ground and air facility requirements, and various aircraft configurations and technologies (see figure 3A-1). The summary final report, *Civil Tiltrotor Missions and Applications: A Research Study,* published in July 1987, concluded that a 39-passenger version with a pressurized fuselage had significant market potential resulting from reduced ground transportation requirements, congestion relief, and infrastructure investment savings.[2] However, civil tiltrotors would have higher purchase and operating costs than conventional airplanes and would encounter possible stumbling blocks from certification, infrastructure development, public acceptance, and technological maturity. The study concluded that near-term civil tiltrotor development depends on the success of the V-22 program.[3]

NASA and FAA funded a follow-on tiltrotor study[4] by the same contractor team, which financed 45 percent of the project costs. This "Phase II" study focused on the commercial passenger market and investigated in greater detail the operational factors and technology development considerations. The study found that commercial tiltrotor purchase price and operating costs will likely be significantly lower than estimated in the Phase I report, resulting in an expanded potential market. However, the gist of the findings were similar to, but more detailed than, those in the preceding report. Specific urban-to-urban and hub airport feeder routes offering strong market potential were examined in detail. In certain markets, costs to passengers for ground transportation and airline tickets were found to be less via 39-seat commercial tiltrotors traveling between well-situated landing facilities than via trips on similarly sized airplanes flying out of major airports.

The Phase II study recommended forming a public/private partnership of organizations representing Federal, State, and local government and industry interests to create a 4-year program,[5] costing roughly $250 million,[6] to assess the national benefits of a commercial tiltrotor system and to determine if such a system would be feasible. The Phase II study recommended that the Department of Transportation take a leadership role in forming the partnership. Industry and government support and participation would be essential, and the centerpiece of the program would be a series of operational demonstrations using XV-15 and V-22 tiltrotors. Commercial product development or production was not proposed.

Since 1987, FAA has allotted $2.94 million in Airport Improvement Program planning grants to local sponsors across the United States for 17 vertiport feasibility studies. The studies are examining the capital costs and environmental factors in siting vertiports, passenger and shipper demand, traffic forecasts, and the local economics of tiltrotor service. Most of the studies are to be completed by late 1991. FAA and the Volpe National Transportation Systems Center are further examining the cost and market potential of commercial tiltrotors and, through simulations, estimating the effects of tiltrotor operations on airspace congestion and delays.[7]

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[1] Boeing Commercial Airplane Co. et al., *Civil Tiltrotor Missions and Applications: A Research Study,* prepared for Federal Aviation Administration, National Aeronautics and Space Administration, and Department of Defense, NASA CR 177452 (Seattle, WA: Boeing Commercial Airplane Co., July 1987), p. 6.

[2] Ibid.

[3] Ibid., p. 16.

[4] Boeing Commercial Airplane Group et al., *Civil Tiltrotor Missions and Applications Phase II: The Commercial Passenger Market,* prepared for National Aeronautics and Space Administration and Federal Aviation Administration, NASA CR 177576 (Seattle, WA: February 1991).

[5] Ibid., Phase II Summary, p. vi.

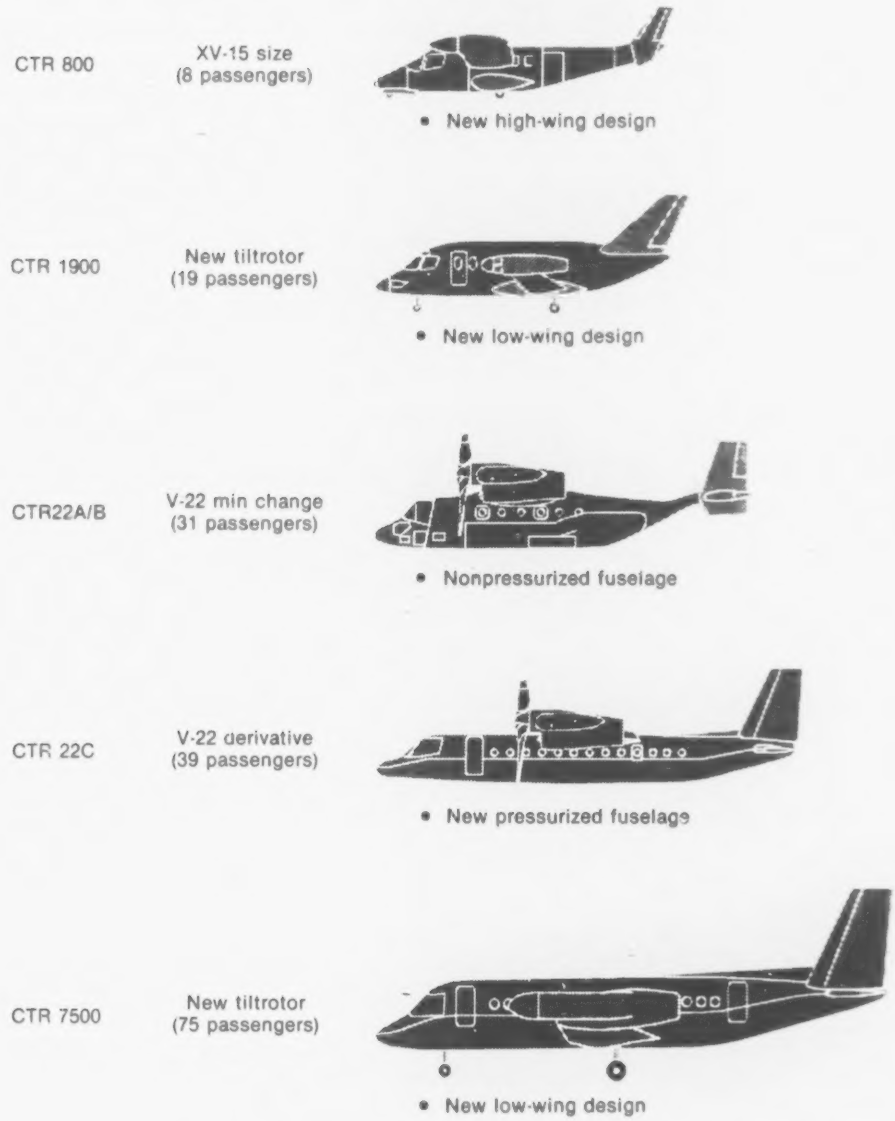
[6] John Zuk, chief, Civil Technology Office, NASA Ames Research Center, personal communication, Apr. 11, 1991.

[7] John P. O'Donnell, Volpe National Transportation Systems Center, personal communication, June 28, 1991.

Continued on next page

Box 3-A, continued

Figure 3A-1—Tiltrotor Configurations


CTR 800
XV-15 size
(8 passengers)
• New high-wing design
CTR 1900
New tiltrotor
(19 passengers)
• New low-wing design
CTR22A/B
V-22 min change
(31 passengers)
• Nonpressurized fuselage
CTR 22C
V-22 derivative
(39 passengers)
• New pressurized fuselage
CTR 7500
New tiltrotor
(75 passengers)
• New low-wing design

SOURCE: Boeing Commercial Airplane Co. et al., *Civil Tiltrotor Missions and Applications: A Research Study*, prepared for Federal Aviation Administration, National Aeronautics and Space Administration, and Department of Defense, NASA CR 177452 (Seattle, WA: Boeing Commercial Airplane Co., July 1987).

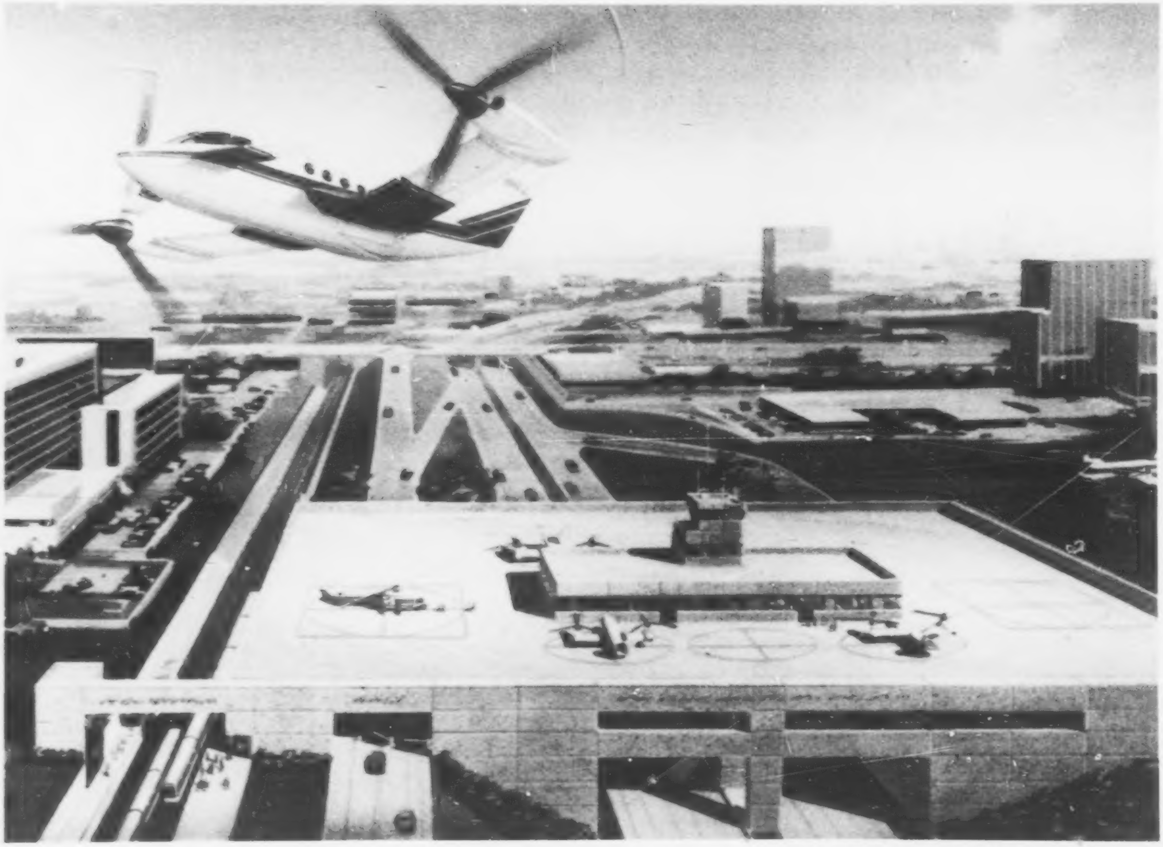


Photo credit: Bell Helicopter Textron, Inc.

Accessible vertiports (shown in this artist's conception) will be crucial to intercity commercial tiltrotor service.

infrastructure, especially the number of available runways. However, most metropolitan areas have few options for expanding airports or their surrounding highways. Commercial tiltrotors offer the potential, under various operating and public policy scenarios, to avoid ground and air congestion, relieve some airport congestion, and increase the capacity of constrained airports. The prime markets for tiltrotor operations are expected to be intercity passenger and airport feeder service in the busiest air corridors. The Phase II Civil Tiltrotor Report by NASA and FAA indicates that some passengers would have shorter and less costly drives to get to a tiltrotor terminal than to an airport, which would save significant time overall and make door-to-door travel costs comparable to using fixed-wing aircraft service from major airports.[15]

Successful commercial tiltrotor service hinges on well-situated landing facilities, or vertiports. Since tiltrotors do not need long runways, 5-acre or smaller vertiports might be built at accessible locations where conventional airports would be environmentally unfeasible or prohibitively expensive, such as over interstate highways or near industrial facilities. Vertiports co-located with airports could permit increased flights to the airport without clogging runways. To take advantage of its flight capabilities, tiltrotors will require some new air traffic control (ATC) technology and

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[15] Boeing Commercial Airplane Co. et al., *Civil Tiltrotor Missions and Applications: A Research Study*, op. cit., footnote 8.

Table 3-1—Tiltrotor System Description

Component	Description	Estimated costs
Tiltrotor aircraft	A twin-engine commercial tiltrotor derived from the military V-22 would be comparable to a medium-size commuter turboprop and could carry around 40 passengers up to 600 miles. It would be capable of vertical takeoff and landing, but short takeoff and landing rolls would improve payload or range. Tiltrotors could use existing airports, but 40-seat versions would be too large for many heliports. To compete with airline shuttle service, passenger cabin noise, vibration, and overall comfort levels will have to be at least equivalent to that of the newest commuter aircraft, such as the Boeing/DeHavilland *Dash 8-300*.	Compared with turboprop aircraft, a tiltrotor would cost around 40 to 45 percent more to produce and about 14 to 18 percent more to operate (over a 200-mile trip).
Vertiports	Vertiports could ideally be located closer to intercity transportation destinations and origins than are major airports. Design depends on location, but theoretically any site with up to 5 acres and necessary surrounding clear zones and compatible land use. Possible locations include air rights above freeways, waterfronts, parking garage rooftops, industrial areas, and existing small airports, and each vertiport could serve about 1 million passengers annually.	$30 million to $40 million for an elevated metropolitan vertiport.
En route airspace	En route between cities, commercial tiltrotors would fly in the same relatively uncongested airspace between 10,000 and 20,000 feet above sea level used by commuter turboprops. Since tiltrotors are smaller than the aircraft they would replace (in intercity service), more flights would operate in the airspace system for the same passenger total.	Tiltrotors are effectively turboprop aircraft when flying en route, so the marginal ATC costs would be the same as those for conventional commuter aircraft. Increased numbers of aircraft operations might require additional air traffic controller positions and facilities.
Terminal airspace	In the airspace surrounding vertiports, optimal flight paths would avoid conflicts with fixed-wing aircraft and permit the steep approaches necessary to minimize tiltrotor community noise levels. This requires ATC procedures and technologies different from those currently used for fixed-wing aircraft and helicopters. Some of these procedures and technologies exist or are being developed. Potential instrument approach paths are steep (6 to 15 degrees) compared with current helicopter and fixed-wing aircraft procedures (3 degrees or less). Operations must not conflict with existing airport traffic patterns.	Other aircraft types would use these technologies and procedures, so development costs need not be attributed solely to tiltrotor.

KEY: ATC=air traffic control.

SOURCE: Office of Technology Assessment, 1991, based on data from Boeing Commercial Airplane Group et al., *Civil Tiltrotor Missions and Applications Phase II: The Commercial Passenger Market*, prepared for National Aeronautics and Space Administration and Federal Aviation Administration, NASA CR 177576 (Seattle, WA: Boeing Commercial Airplane Group, February 1991).

procedures. Additionally, tiltrotor operations must be viewed as acceptable by the local communities, the traveling public, airlines, and financiers. Table 3-1 describes the basic components of a commercial tiltrotor transportation system.

Conceptually, a network of 12 strategically located vertiports could handle most of the intercity passenger air traffic projected for the Northeast Corridor (NEC) in 2000.[16] Frequent tiltrotor departures to each destination (30- to 60-minute intervals)[17] would reduce total trip times for passengers by one-third (more than an hour) on average relative to existing airline schedules. (Table 3-2 lists the characteristics of a hypothetical NEC tiltrotor system.) Most of the time saved would result from shorter ground trips to and from terminals.

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[16] Boeing Commercial Airplane Group et al., Phase II Summary, op. cit., footnote 8, p. 20.

[17] Depending on time of day, this is comparable to current flight frequencies between some of the major Northeast Corridor airports.

Table 3-2--Characteristics of a Hypothetical Northeast Corridor Tiltrotor System for Year 2000

Passenger volume	14 million passengers annually[a]
Vertiports	12 nonairport metropolitan locations[b]
Tiltrotor fleet..........	164 40-seat aircraft
Operations	1,524 flights per day[c]
Average trip length	223 miles

[a] Boeing Commercial Airplane Co. forecast. Around 8 million airline passengers traveled between the major Northeast Corridor airports in 1989.

[b] The location and number of vertiports are: New York (6); Boston (3); Washington, DC (2); and Philadelphia (1).

[c] Approximately 250 or so flights per day by passenger airlines currently operate between the major Northeast Corridor airports.

SOURCE: Office of Technology Assessment, 1991, based on data from Boeing Commercial Airplane Group et al., *Civil Tiltrotor Missions and Applications Phase II: The Commercial Passenger Market*, prepared for National Aeronautics and Space Administration and Federal Aviation Administration, NASA CR 177576 (Seattle, WA: Boeing Commercial Airplane Group, February 1991).

State of the Technology

VTOL research vehicles that can also operate as fixed-wing aircraft have flown since the 1950s (see box 3-B)—most were initially investigated for military purposes. Modern digital electronic controls, advanced lightweight materials, and more powerful engines have made these concepts more practical for operational use, but only helicopters and vectored-thrust jets (e.g., the AV-8B *Harrier* jumpjet) have gone into production.

Military and Civilian Tiltrotor Programs

Military decisions in the early 1980s to develop a multiservice tiltrotor aircraft sparked the interest of some in the civil aviation community who thought that the technology, industrial base, and operational experience of military tiltrotors would help overcome many of the hurdles facing a commercial vehicle. The V-22 full-scale development program began in 1986 under contract to Bell Helicopter Textron, Inc. and Boeing Helicopter Co., and the technical results to date have been promising. First flown in March 1989, the V-22 has demonstrated flight with rotors tilted in all positions and cruise speeds up to 328 miles per hour (mph).[18] The proof-of-concept predecessor to the V-22, the NASA/DOD XV-15 tiltrotor research aircraft, was developed in the 1970s. Two aircraft were built, and both are still being used in civilian flight investigations, such as determining tiltrotor adaptability to urban vertiports.

Over $2.2 billion for V-22 development has been spent or allocated since 1983, but the future of the V-22 is precarious. The program was canceled by DOD in fiscal years 1990 and 1991 budget proposals, only to be reinstated by Congress each time. DOD again requested no funds for the V-22 in fiscal year 1992, and at the time this report went to press, House and Senate Committees on Armed Services had passed authorization bills that included V-22 funding for fiscal year 1992. Full-scale development, including flight tests, has continued, but no production funds have been used. If the V-22 program is continued, limited numbers of military aircraft could be produced by early 1995.[19]

No U.S. company has committed to developing a tiltrotor for revenue passenger operations, and airlines have shown little interest in this technology. Predesign and planning studies have been funded primarily by the Federal Government, with some cost-sharing by industry and local governments. NASA and FAA continue to develop technologies applicable, but not necessarily specific, to tiltrotor.

Other High-Speed VTOL Aircraft Programs

Presently, there is little VTOL aircraft competition for the intercity transportation markets that a commercial tiltrotor could serve. New helicopters, such as the Westland/Augusta EH-101, could carry 30 passengers at 150 mph on trips up to 500 miles, but operating and maintenance costs are higher than the figures projected for a civil tiltrotor. It is generally believed that a VTOL aircraft would have to combine some

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[18] Norwine, op. cit., footnote 10.

[19] Ibid.

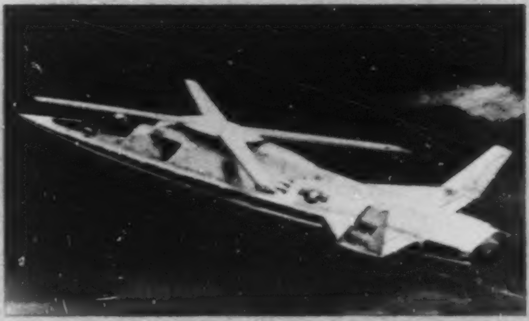
Box 3-B—VTOL Concepts

Advanced vertical takeoff and landing (VTOL) aircraft designs aim to exceed the speed and range of helicopters by overcoming rotor aerodynamic limitations. Rotating blades are both the "propeller" and the "wings" for helicopters, and this duality is the key factor that restricts helicopter performance. When a

Bell UH-1

Sikorsky ABC (XH-59A)

Bell XV-3



X-Wing

Hawker Siddley Harrier Jet

Photo credit: Bell Helicopter Textron, Inc. (XV-3); Sikorsky Aircraft Division of United Technologies

A wide range of vertical takeoff and landing aircraft that could fly faster than conventional helicopters have been examined.

Box 3-B, continued

helicopter hovers, each of its rotorblades experiences the same airflow over its surfaces. As the helicopter moves forward, the retreating rotorblades encounter lower relative winds. Maximum practical helicopter speeds are limited to around 200 miles per hour (mph),[1] at which point the airflow across the retreating blades stalls, causing severe vibration and control problems. Various advanced VTOL aircraft concepts are shown in the photos in this box and some are discussed below.

Compound Aircraft

Some of the lift and propulsive loads on helicopter rotors can be shifted to additional wings and horizontal thrust engines, permitting such a compound helicopter to fly well above 200 mph. A Bell UH-1 helicopter modified with two high-thrust jet engines reached 315 mph. Sikorsky Aircraft Division developed a compound rotorcraft that used two counter-rotating, coaxial rotors for lift, called the advancing blade concept (ABC).[2] Using two horizontally mounted turbojet engines for propulsion, the experimental Sikorsky ABC (XH-59A) reached 275 mph in level flight.

These Bell and Sikorsky compound helicopters were propelled by separate jet engines, making them impractical for commercial purposes. The first compound helicopter using the same engines to power the rotors and to provide significant thrust was the Piasecki 16H-1. A later version, the 16H-1A, reached 225 mph in 1964.[3]

Houston-based Vulcan Aircraft Corporation has been developing a design with lifting fans embedded in the wings. This fan-in-wing concept would receive vertical thrust from the fans for takeoff and landing, then close off the fan disks with louvers and propel itself with jet thrust from the two horizontally mounted engines (which also power the fans). Vulcan's 6-seat aircraft is designed to fly 500 miles and 350 mph. Because the fan disks are relatively small, fan-in-wings require about 10 times more power than a helicopter to lift the same payload.

Tilt-Thrust Designs

Tiltwing and tiltrotor aircraft use the same rotors or propellers for both vertical and horizontal thrust by redirecting the whole wing or the rotor systems only, reducing weight and drag penalties relative to compound helicopters. Lift during cruise is provided by a wing, and maximum speeds are in the turboprop aircraft range of 400 mph. Tiltrotors and tiltwings are design compromises between helicopters and airplanes—their rotors/propellers are too small to hover as well as those of helicopters but too large to be efficient in cruise flight. In 1958, the Bell XV-3 became the first tiltrotor to successfully takeoff like a helicopter and then convert to the airplane mode.

Stowed or Stopped Rotor Concepts

Compound helicopters capable of stopping rotors in flight and folding them up or converting the rotors into fixed wings have the highest speed potential of any rotorcraft configuration. One design strategy is to fly the rotorcraft fast enough to transfer lift to separate wings and then stop and fold the rotors. From this point in cruise flight, the aircraft is basically an airplane, and maximum speed is a function of aerodynamic design and engine power. Rotor blades, which are generally flexible, are difficult to stop or start during forward flight because of the severe stresses and forces resulting from the blades' flapping in the wind. A stowed- or stopped-rotor aircraft has never flown. However, full-scale models of both stowed- and stopped-rotor systems

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[1] The world speed record of 248 miles per hour was set by a modified Westland Lynx helicopter in 1986. E.A. Fradenburgh, *Overview of Helicopters and V/STOL Aircraft and Basic Aerodynamics for Rotor Performance*, Advisory Group for Aerospace Research & Development, North Atlantic Treaty Organization (AGARD, Neuilly Sur Seine, France: Advisory Group for Aerospace Research & Development, 1990), p. 4.

[2] The advancing blades, balanced on both sides of the aircraft, provide most of the lift. Lift from the retreating blades is not critical, and airflow stall is avoided.

[3] F.N. Piasecki, president, Piasecki Aircraft Corp., personal communication, July 2, 1991.

Continued on next page

Box 3-B, continued

have been tested in the National Aeronautics and Space Administration (NASA) wind tunnels at Ames Research Center.[4]

NASA and the Defense Advanced Research Projects Agency developed and tested technologies for a different concept with very high-speed potential during the 1980s called an X-wing, but the program has been scaled back to a low-level research effort. A four-bladed rotor provides vertical thrust like a helicopter rotor for takeoff and low-speed flight and is stopped and locked into an "X" position relative to the fuselage and serves as a wing for high-speed cruise. The X-wing design, if lightweight enough, could hover as efficiently as a helicopter and fly as fast as a jet.

Vectored-Thrust Vehicles

Deflecting horizontal thrust downward to provide lift has been practical only for jet-powered designs, since this concept requires the most power to lift each pound of aircraft and payload in vertical flight. The British Aerospace/McDonnell Douglas AV-8B *Harrier* jet, currently in service with the U.S. Marine Corps, is a vector-thrust vehicle.

All these VTOL concepts pay a price for speed. Useful payload is always less than that carried by a comparably sized helicopter, speed and range are always less than for similar airplanes, and complexity is greater than in helicopters or airplanes. However, the combination of payload, speed, and range may make one of these compromise designs the optimal choice, depending on mission requirements and economics.

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[4] John F. Ward, president, Ward Associates, personal communication, June 28, 1991.

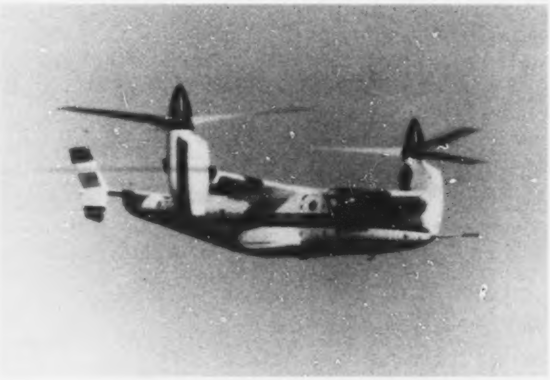

Photo credit: Bell Helicopter Textron, Inc.

After more than a decade of service, two XV-15 research aircraft continue to test and demonstrate tiltrotor technology and flight procedures.

elements of fixed-wing performance to penetrate the intercity transport market significantly. Eurofar has a 30-seat commercial tiltrotor on the drawing board, but the program is probably about 5 years behind U.S. tiltrotor efforts.[20] A U.S. company, Magnum T/R Inc., of Salinas, California, is proposing to build a 9-seat tiltrotor based on XV-15 technology for the general aviation market.

Ishida Aerospace Research, Inc., a subsidiary of the Ishida Group in Japan, could become the first company producing a high-speed VTOL aircraft for the civilian market. Now in the design stage, Ishida's TW-68 tiltwing aircraft could perform competitively with a civil tiltrotor and be delivered to its first customer in 1997. The 14-passenger TW-68 is aimed at the private market, such as corporate travel, rather than commercial transportation, although Ishida is applying for the more stringent FAA certification to permit tiltwings to be used in airline operations. Other tiltwing experience includes the LTV-Hiller Ryan XC-142 and the Canadair CL-84 aircraft programs, which developed flying prototypes in the late 1960s and early 1970s.

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[20] U.S. Federal agencies and industry have had many years of experience in developing and testing tiltrotor technology. However, timing for commercialization depends on additional factors, making it difficult to quantify a "lead."

Photo credit: Ishida Aerospace Research, Inc.

The Ishida TW-68 tiltwing is designed for industrial and corporate service, and is expected to be developed and produced in Texas.

To the casual observer, a tiltwing looks and operates like a tiltrotor. However, the Ishida design, unlike the V-22, does not incorporate helicopter systems—it uses propellers, not rotors.[21] Ishida expects this simpler technology to keep tiltwing capital and maintenance costs lower than those of comparable tiltrotors.[22] Since the wings tilt up for vertical flight, there is less adverse downwash on the vehicle, which helps takeoff power requirements. Unlike VTOL aircraft as large as the V-22 (roughly 40,000 pounds), the 14,000-pound TW-68 will be capable of using most existing heliports.

Many industry observers consider the tiltwing technically riskier than the tiltrotor.[23] Possible tiltwing disadvantages, relative to a tiltrotor, are the added weight from mechanisms capable of tilting a full wing and engines, less vertical flight and hover capabilities, and poorer control and higher noise levels in vertical and transitional flight.[24]

Research, Development, and Demonstration Needs for Commercial Tiltrotor Systems

Commercial tiltrotor designs were considered technically feasible by all aviation experts contacted by OTA. Fundamental tiltrotor principles have been proven, and advanced flight test vehicles have flown for over a decade. However, factors critical to commercial success have yet to be demonstrated, including operational reliability and economics, exterior and interior noise levels, and community and passenger acceptance. Moreover, supporting infrastructure—vertiports, facilities, and air traffic procedures—would have to be developed and put in place to make tiltrotor commercially practical.

Commercial Tiltrotor Aircraft Issues

Regardless of decisions on the V-22 program, precompetitive technology development and testing applicable to all civil tiltrotor (and most other civil VTOL aircraft) designs will be necessary prior to industry commitment to produce commercial tiltrotors. Most observers believe that the V-22 *Osprey* design is unacceptable for commercial operations, owing to economic and civil performance penalties inherent in meeting military requirements, although some V-22 structural and propulsion designs and components might be directly transferred to a commercial tiltrotor. Options to create a V-22 derivative for commercial transportation mostly involve design tradeoffs that will depend on market economics, certification requirements, and industry decisions, and are not discussed here.[25] Rotor noise reduction, cockpit design, and steep-angle flight systems are the main generic (R&D) needs to help make tiltrotors commercially practical.

Noise—There is common agreement that the issues related to aircraft noise in communities are major obstacles to commercial tiltrotors, since their success-

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[21] There is no inherent reason preventing a tiltwing from using rotors or a V-22-type vehicle from using propellers, provided complementary control devices are also installed. Rotors are more complicated than propellers, enabling them to provide lift as well as power in forward flight.

[22] David Kocurek, president, Ishida Aerospace Design, Inc., personal communication, Dec. 4, 1990.

[23] E.A. Fradenburgh, director, Research and Advanced Design, Sikorsky Aircraft Division, personal communication, Feb. 12, 1991.

[24] Philip C. Norwine, vice president, Commercial Market Development, Bell Helicopter Textron, personal communication, Oct. 12, 1990; Fradenburgh, op. cit., footnote 23; and Robert Whitehead, assistant director for Aeronautics (Rotorcraft), National Aeronautics and Space Administration, personal communication, Feb. 6, 1991.

[25] The Phase II report addressed at length commercial standards for a V-22 derivative.

Table 3-3—Noise Data and Federal Noise Standards for Aircraft

Airplane noise location	FAA noise standard[a] (EPNdB)[b]	40-seat tiltrotor noise[c] (EPNdB estimate)	40-seat airplane noise[d] (EPNdB actual)
Under takeoff path (6,500 meters from brake release)	89.0	60.0	80.8
To the side of takeoff path (450 meters from the point where noise is greatest)	94.0	74.0	86.3
Under landing approach path (2,000 meters from the landing threshold)	98.0	77.0	94.8
Rotorcraft noise location	FAA noise standard (EPNdB)	40-seat tiltrotor noise (EPNdB estimate)	44-seat helicopter noise[e] (EPNdB actual)
Under takeoff path (point where altitude is 150 meters)	101.6	78.0	96.2
To the side of takeoff path (150 meters from the point where noise is greatest)	102.6	84.0	97.2
Under landing approach path (point where rotorcraft altitude is 120 meters)	103.6	77.0	102.1

[a] Noise standards vary by aircraft weight; those listed here are for aircraft around 40,000 pounds. See 14 CFR 35 for further information.

[b] Effective perceived noise decibels (EPNdB) is an objective measure of noise that gives extra weight to those sound frequencies that are most annoying to the human ear. See 14 CFR 36 for further information.

[c] For a new commercial tiltrotor, not the military V-22.

[d] For a DeHavilland DHC-8-102.

[e] For a Boeing Helicopter BV-234.

SOURCE: Boeing Commercial Airplane Co. et al., *Civil Tiltrotor Missions and Applications: A Research Study*, prepared for Federal Aviation Administration, National Aeronautics and Space Administration, and Department of Defense, NASA CR 177452 (Seattle, WA: Boeing Commercial Airplane Co., July 1987), p. 43.

ful operation will depend on flights to destinations that currently experience little aircraft noise.[26] However, tiltrotor engineers predict that less noise will reach the ground from tiltrotors than from similarly sized helicopters or airplanes,[27] and that tiltrotor noise could be significantly reduced through technological and procedural developments.[28]

Hover and cruise performance have been emphasized at the expense of noise in the designs of most military and civilian rotorcraft, including the V-22. For example, increasing the number of rotor blades and optimizing their shape could potentially reduce noise and vibrations. However, relatively little Federal or industry research has been devoted to this effort.

Tiltrotors are expected to be quieter in the cruise mode than most aircraft, and steep flight paths lessen noise levels on the ground because they decrease power required for approach, keeping tiltrotors high for as long as possible over communities, and reducing time required and ground distance covered during the descent. However, the minimum-noise flight profile to convert from cruise to landing has to be validated. Bell Helicopter Textron and NASA-Langley are collecting noise data for XV-15 takeoffs and landings, but measurements are not yet available for the larger V-22 tiltrotor.[29] (Table 3-3 compares estimated tiltrotor noise with other aircraft noise levels.)

Aircraft cabin noise levels will benefit from any effort to reduce rotor noise at the source. Additionally, passive insulation, active noise suppression techniques, and rotor tip-fuselage separation are market-responsive design issues for lowering interior noise and are possible areas for more study.

Cockpit Designs and Procedures—Depending on the phase of flight, a tiltrotor will operate like a helicopter or like a conventional turboprop airplane. Currently, helicopter and airplane cockpits are distinctly different, which is one reason why FAA certifies helicopter pilots separately from airplane pilots. Computerized control systems permit hybrid cockpit designs, and future airline fleet standardization and pilot career paths must be considered in developing commercial tiltrotor cockpits and procedures. Recent investigations indicate that the V-22 cockpit design, a compromise between military fixed-wing aircraft and helicopter cockpits, is not appropriate for commercial operations.[30]

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[26] However, ambient noise from other industrial or transportation sources might be louder than tiltrotors (e.g., for vertiports built above freeways).

[27] Boeing Commercial Airplane Group et al., Phase II Draft Final Report, op. cit., footnote 8, p. 1-2.

[28] Boeing Commercial Airplane Group et al., Phase II Summary, pp. 34-36.

[29] Ibid., p. 35.

NASA and FAA have conducted limited tiltrotor landing profile analyses using the V-22 flight simulator modified to reflect commercial tiltrotor characteristics. Pilots from various organizations who flew different instrument approach profiles and rated flying quality and workload[31] generally preferred 12- to 15-degree descents.[32] These simulations were limited to no-wind conditions and constant-speed descents with deceleration to vertical landing, which pilots found relatively easy to fly.[33] Curved or segmented approaches, flight profiles for short takeoffs and landings, and the effects of winds and turbulence were not examined. Moreover, all the pilots had fundamental problems with flight deck controls—each pilot moved the thrust and/or nacelle control levers the wrong way at least once during the simulated flights. Further research actively involving the airline industry and experts in human factors[34] will be necessary for determining appropriate tiltrotor cockpit layouts and pilot certification criteria for safe operations.

Steep Angle Approach—The ability to fly optimal noise reduction profiles discussed above goes hand in hand with navigation and guidance technology development. For noise reduction, pilot workload, and safety reasons, tiltrotor operations would optimally use 12- to 15-degree approach paths. Recent simulator studies indicate that approach and descent angles up to 25 degrees might be feasible under visual flight conditions.[35] These proposed angles are significantly steeper than the approximately 3-degree glideslopes common to all precision instrument approaches used at public airports in the United States.

FAA is investigating the airspace procedures and Microwave Landing System (MLS) technology (explained later) for steep flight paths, and NASA continues to study pilot and aircraft performance in simulators. Aircraft airspeed indicators are inherently inaccurate at low speeds, so new or different instruments will have to be developed and proven to permit steep approaches during poor weather conditions. However, the basic capability for automatic helicopter approach from altitude under instrument flight conditions was demonstrated by NASA over 20 years ago.[36]

Infrastructure Issues

Commercial tiltrotor operations from urban vertiport or airport locations will require new ground facilities, ATC equipment, and procedures for terminal airspace. Most of the necessary technologies and procedures are in various stages of development by FAA, but potential tiltrotor manufacturers and customers have to be confident that this new infrastructure will be validated and installed in time to support commercial operations. FAA expects its multiyear Capital Improvement Program (formerly called the National Airspace System Plan) to modernize the ATC system to expand the capacity of en route airspace over the next decade. However, if some jet shuttle passengers shift to 40-seat tiltrotors, three to five tiltrotor aircraft would enter the ATC system for each jetliner replaced.

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[30] Ibid., Phase II Summary, p. 29.

[31] The Cooper-Harper scale, a standard aviation industry tool for quantifying subjective pilot opinions of aircraft handling qualities, was used in this investigation. See G.E. Cooper and R.P. Harper, "The Use of Pilot Rating in the Evaluation of Aircraft Handling Qualities," NASA TN D-5153, unpublished report, April 1969.

[32] Boeing Commercial Airplane Group et al., Phase II Summary, op. cit., footnote 8, p. 42.

[33] Ibid., Phase II Draft Final Report, p. 1-2

[34] Human factors, a discipline combining behavioral science and engineering, focuses on improving the performance of complex systems of people and machines. Designing and operating a system so that it does not induce human error is one critical component of human factors and limiting the impact of a human error once it occurs is another aspect.

[35] John F. Ward, president, Ward Associates, personal communication, June 28, 1991. However, approach angles will likely be limited to less than 25 degrees due to the aircraft's obstruction of the pilot's view of the landing zone and aircraft control limitations due to wind gusts that become a larger fraction of forward speed the steeper the approach angle becomes.

[36] John F. Ward, "To Capture the Market, Put the Real 'V' in VTOL," *Vertiflite*, an American Helicopter Society Publication, vol. 37, No. 1, January/February 1991.

The safety and congestion implications of this new traffic will have to be assessed if commercial tiltrotor operations progress to that stage. Moreover, terminal facilities and airspace procedures for VTOL aircraft are not current FAA priorities, although they could be ready within the decade, given sufficient Federal, State, and local government support.

Terminal Navigation and Guidance Equipment—MLS, scheduled to become the international standard for precision instrument approaches beginning in 1998, has the capability to provide both steep-angle and curved-path descent guidance important for commercial tiltrotor operations. In addition to validating such flight procedures, MLS equipment must be developed and approved for use at small facilities such as heliports or vertiports. MLS is currently installed at two heliports for tests and evaluations, and FAA expects to publish criteria for helicopter instrument approaches for heliports with MLS equipment by early 1992.[37] In MLS, guidance signals spread out like a cone from the transmitting antenna, and the reception area narrows as the aircraft approaches for landing. Due to space limitations, the MLS azimuth antenna (which sends lateral guidance signals) will likely be located within a few hundred feet of the landing area at vertiports, possibly prohibiting some desirable flight paths. Azimuth coverage is not a problem for conventional airports where the transmitting antenna is positioned at the opposite end of the runway (possibly 2 miles away) from the approach path.

Line-of-sight obstructions in urban areas could impede conventional communication and radar surveillance systems. Satellite-based systems and LORAN,[38] two technologies used extensively by the military for long-range communication, navigation, and surveillance, are in limited, but growing, service in civilian aviation. FAA has programs scheduled over the next decade to investigate and design low-altitude ATC applications for these systems.

Airspace Procedures—Developing safe en route and terminal flight procedures is a well-established task for FAA. However, bringing together new aircraft and ATC technologies while ensuring pilot and controller adaptability adds complexity and represents an important additional issue for FAA. The agency is modifying existing rotorcraft terminal instrument procedures (TERPS) to allow helicopters and future tiltrotors to use flight paths made possible by new avionics. Commercial tiltrotors might require more complex procedures (e.g., steeper glideslopes) than those allowed by generic rotorcraft TERPS to conduct flights at environmentally sensitive vertiports. Tiltrotor proponents fear that a conservative approach by FAA to developing standards for these procedures and airspace could delay or stymie industry support for commercial tiltrotors.[39] Since a suitably equipped tiltrotor is not currently available, FAA plans to use flight simulators to develop tiltrotor TERPS, but will not certify the TERPS until they are safely demonstrated with actual aircraft.

Federal Programs for Civil Tiltrotor Development

Rotorcraft-related programs in FAA, NASA, and DOD help civil tiltrotor development, as do generic aviation R&D in lightweight structures and materials, engine performance, simulations, human factors, and aircraft and ATC systems. The Federal Government has spent almost $27 million over the past 5 years for civilian or dual-use tiltrotor technology programs (see table 3-4).

National Aeronautics and Space Administration—NASA, together with DOD and industry, has investigated and developed tiltrotor technology since the 1950s. The XV-15 program was a successful proof-of-concept demonstration that lead to the V-22 program. Two XV-15 aircraft are currently being used by NASA and Bell Helicopters for civil noise and terminal airspace procedures flight testing.

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[37] Robert Chenney, Aviation National Standards Field Office, Federal Aviation Administration, personal communication, July 24, 1991.

[38] LORAN is a low-frequency radio navigation system, operated by the Coast Guard, that transmits useful signals up to 1,000 miles away. Bulky and complex LORAN receivers were designed originally for marine operations, but low-cost/low-weight signal processors now make LORAN measurements practical for aviation.

[39] P.R. Thompson, Boeing Commercial Airplane Group, OTA workshop discussion, Apr. 18, 1991.

Table 3-4—NASA and FAA Budgets for Tiltrotor and Other Vertical Flight Technology Programs

	FY 1988	FY 1989	FY 1990	FY 1991	FY 1992	5-year total
	(real year dollars in millions)					
NASA:						
Tiltrotor	3.5	3.8	5.0	5.0	5.2	**22.5**
Rotorcraft, including tiltrotor	22.0	23.9	21.7	24.3	25.3	**117.2**
Total aeronautics	332.9	398.2	442.6	512.0	591.2	**2,276.9**
FAA:						
Tiltrotor[a]	1.9	1.0	0.7	0.4	0.4	**4.5**
Vertical flight RE&D[b]	2.8	4.2	4.2	4.3	5.2	**20.6**
Total FAA RE&D[c]	173.8	162.3	212.7	244.6	262.0	**1,055.4**
Total for civil tiltrotor	5.4	4.8	5.7	5.4	5.6	**26.9**
Total for rotorcraft/vertical flight technology	24.8	28.1	25.9	24.7	25.7	129.2

[a] Includes civil tiltrotor studies, vertiport planning, and V-22 certification expenditures.

[b] Does not include vertiport planning and certification expenditures.

[c] Includes funding for facilities.

KEY: NASA = National Aeronautics and Space Administration; FAA = Federal Aviation Administration; FY = fiscal year; RE&D = research, engineering, and development.

SOURCE: National Aeronautics and Space Administration, 1991; Federal Aviation Administration, 1991; and American Association for the Advancement of Science, 1990.

Specifically for tiltrotor, NASA research focuses on improving the performance of the vehicle and integrating tiltrotors into the civil aviation system.[40] Among the current (and planned) NASA investigations are: ways to limit the adverse forces on the wings from hover downwash; reducing rotor noise and vibrations through new designs, materials, and controls; developing simulation models; studying unique tiltrotor cockpit automation and human factors issues; and exploring higher speed tiltrotor configurations. Additionally, NASA conducts long-range, generic R&D in aeronautics technology, such as low-weight materials and advanced propulsion technologies, that could have a direct effect on civil tiltrotor.[41] NASA spends $25 million annually for rotorcraft-related R&D, with about one-fifth of that specifically for tiltrotor. (See table 3-4 again.)

Federal Aviation Administration—FAA, as the Federal agency responsible for ensuring civil aviation safety and promoting air commerce, has been involved in vertical flight certification and infrastructure development since the creation of a civil rotorcraft industry following World War II. In 1985 FAA proposed a joint study with DOD and NASA to investigate the civil potential of tiltrotors and capitalize on the ongoing military technology development. In 1988 FAA established the Civil Tiltrotor Initiative to ease nonmilitary implementation of tiltrotors should demand for such service materialize. Under this program, FAA has accelerated the tiltrotor certification process by gathering early engineering and test data from the military V-22 test program and developed aircraft and operational certification criteria. FAA estimates that the V-22 could be certified for demonstration purposes by 1995 and a civil design could be approved by 1998, saving 5 to 8 years over a sequential certification process.[42]

Reflecting the level of civil rotorcraft use in the United States, FAA rotorcraft R&D programs are relatively small (see table 3-4). The $4-million average annual rotorcraft R&D expenditure over the past 5 years was 2 percent of FAA's total R&D budget. FAA rotorcraft R&D focuses on infrastructure development and aircraft safety, such as terminal instrument procedures, aircraft simulation, ATC procedures, and communication, navigation, and surveillance systems. Specifically for tiltrotor, R&D funding goes to initial planning for a civil demonstration program and coordination with NASA tiltrotor technology R&D efforts. Additionally, FAA has awarded just under $3 million in Airport Improvement Program Grants for 17 vertiport planning and feasibility studies and $600,000 has been funded through the end of fiscal year 1991 to collect precertification data from the V-22 and to develop terminal airspace procedures.[43]

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[40] Robert Rosen, deputy associate administrator for Aeronautics, Exploration, and Technology, National Aeronautics and Space Administration, testimony at hearings, in U.S. Congress, House Committee on Science, Space, and Technology, Subcommittee on Transportation Aviation and Materials, *Civil Tiltrotor Applications Research* (Washington, DC: U.S. Government Printing Office, July 17, 1990), p. 141.

[41] Ibid., pp. 141-143.

[42] U.S. Department of Transportation, Federal Aviation Administration, *Rotorcraft Master Plan* (Washington, DC: November 1990); and Michael Zywokarte, NYMA, Inc., personal communication, July 24, 1991.

Market and Economic Evaluation

The market for commercial tiltrotor aircraft and service is speculative, given that neither the vehicle nor the required infrastructure exists. Since a tiltrotor will cost more per seat to purchase and operate than a similarly sized or larger conventional airplane, other factors must be important if commercial tiltrotor service is to be economical. The basis for commercial tiltrotor market potential is avoiding, and possibly relieving, air and ground congestion. There might be national competitiveness and technical readiness benefits stemming from U.S. tiltrotor technology and industrial base development, although such benefits are not analyzed in this report.

The value of commercial tiltrotor passenger or freight service relative to other air travel options lies mainly in two areas: 1) improving door-to-door trip times for passengers (or cargo) by circumventing ground and air congestion, and 2) expanding the capacity and reducing the runway congestion at the busiest airports by permitting some short-haul traffic (trips of less than 500 miles) to shift to tiltrotors, thus freeing runway space for larger aircraft. Whether these benefits are sufficient for industry to produce commercial tiltrotors and for airlines to operate them is unclear.

Public data are sparse on door-to-door travel and passenger perceptions of ground access costs and value of time, making demand projections difficult. Another uncertainty is the willingness of hub feed commuter airlines, most of which are affiliated with major air carriers, to switch to tiltrotors without new Federal and local government policies. Moreover, how much traffic could be diverted from generally lower cost automobile trips and other nonair travel modes or otherwise be generated by the time-saving potential of tiltrotor is not well understood. Hence, only airline traffic between urban areas is considered as the initial market base for commercial tiltrotors.[44]

Crucial to commercial tiltrotor service are safe and reliable aircraft, a suitable infrastructure, and willing airline operators. To focus on the markets and economics of commercial tiltrotors, OTA has assumed that the infrastructure could be in place and other possible institutional hurdles could be overcome. (Institutional factors that could impede a commercial tiltrotor system are discussed in the next section.) Much of the background data on tiltrotor economics and markets used in this section comes from the NASA/FAA Phase II study. According to that study, **if a market-responsive tiltrotor and infrastructure were available today, intercity passenger service would be viable in certain markets.** However, further analysis is needed to determine whether there is enough demand to justify producing commercial tiltrotors in the next decade. Moreover, a better understanding is needed about the increases in capacity and the degree of congestion relief to be realized through commercial tiltrotor operations and about what public policy support, if any, might be necessary. The primary reason FAA is studying tiltrotor technology is to reduce air traffic delays.[45]

Tiltrotor Economics

Tiltrotors will not offer improved cost, airspeed, trip frequency, or comfort over existing aircraft serving urban airports; their value depends on overcoming runway and road congestion.[46] For intercity service, a tiltrotor system design would use a distributed network of terminals (as opposed to the more centralized network of existing hub airports) that could allow shorter and quicker ground trips for air travelers. **Other actions to reduce current and projected transportation problems, especially airport congestion, might dilute many of the advantages cited for commercial tiltrotor.** For example, a downturn in the economy, use of larger aircraft, or better management of aviation infrastructure might lessen the pressure on the busiest airports. Moreover, the accuracy of FAA airport congestion forecasts is open to question—projections are based on limited data and do not account for possible changes in air carrier operating practices if the delay costs become too burdensome (see forecasting section in chapter 2).

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[43] Joseph M. Del Balzo, executive director for System Development, Federal Aviation Administration, personal communication, June 10, 1991.

[44] George Unger, National Aeronautics and Space Administration, OTA workshop discussion, Apr. 18, 1991.

[45] Michael Zywokarte, NYMA, Inc., personal communication, July 2, 1991.

[46] Studies indicate that tiltrotors might offer better and more economical service in regions where transportation is difficult, such as Alaska and the Caribbean according to Ted Lane, Thomas/Lane & Associates, personal communication, June 28, 1991.

However, if airport congestion grows over the next decade, there will be few acceptable public options to ameliorate it. Adding new airport capacity will be difficult—communities oppose most plans for new runways and airports, and advanced technologies to squeeze more flights into airports will be slow to come online and will produce marginal improvements at best.[47] Demand management mechanisms, such as runway differential pricing, generate heated protests from users and create issues of social and economic equity that are hard to resolve.[48]

Costs To Build and Operate Commercial Tiltrotors

For a given level of technology, the cost to build and operate an aircraft depends on its payload capacity and design range. Selected commercial tiltrotor designs from 8 to 75 seats with ranges up to 600 miles were considered in the earlier Phase I study.[49] Cost data for commuter airline turboprop airplanes were used to gauge commercial tiltrotor economic estimates, since the size, en route performance, and the nature of airline operations for tiltrotors are assumed to be similar to those for turboprops. The following assumptions were made in the Phase II study:

- Military V-22 production and operating costs are not analogous to commercial tiltrotor costs, owing to differences in mission requirements, materials, military procurement rules, and production rates.
- Only a small percentage of tiltrotor flight time will be in the helicopter mode (e.g., vertical flight would account for 2 percent of a 200-mile trip). This is important because maintenance and fuel costs climb with increased use of vertical flight.
- Generic turboprop and jet aircraft cost data, derived from actual airline and manufacturer figures, are used to estimate and compare tiltrotor economics.
- A commercial tiltrotor would cost 40 to 45 percent more to build than would a turboprop with equivalent size, range, and overall quality.

A 39-seat tiltrotor was found to be a good compromise size for the flight frequency and passenger volumes required for the commercial markets studied by the Phase II team. Such an aircraft is similar in size to the V-22 *Osprey* and might benefit from some common technology and components. However, changes in market factors and closer analysis of potential demand might indicate a different optimal tiltrotor configuration.

The Phase II study team analyzed the costs to build, maintain, and fly a commercial tiltrotor. Some of the findings are provided in table 3-5, which compares economic figures for tiltrotor, turboprop, and jetliner aircraft. For flights longer than around 100 miles, tiltrotors would be more expensive than equivalent turboprops for an airline to operate. However, tiltrotors flying from vertiports could offer significant savings in time and ground transportation costs for passengers who normally travel through major airports, possibly making tiltrotors competitive in certain markets.

If Ishida tiltwings or other high-speed VTOL aircraft go into production, their effect on the airspace system and the demand for commercial tiltrotor service will have to be factored into tiltrotor forecasts. Detailed cost data are not yet publicly available, but

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[47] U.S. Congress, Office of Technology Assessment, *Delivering the Goods: Public Works Technologies, Management, and Financing*, OTA-SET-477 (Washington, DC: U.S. Government Printing Office, April 1991), p. 84.

[48] Ibid., p. 85.

[49] Tiltrotor and conventional turboprop aircraft with 8, 19, 31, 39, 52, and 75 seats were analyzed in the Phase I study.

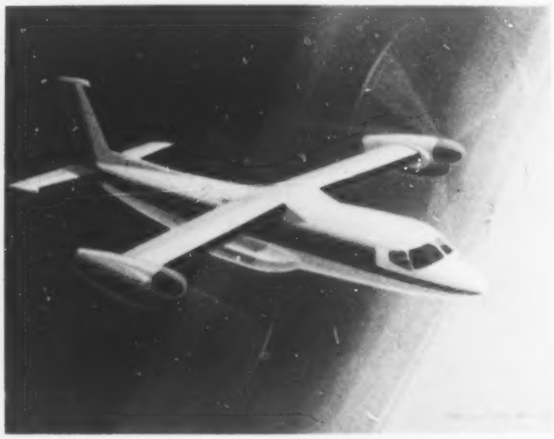

Photo credit: Bell Helicopter Textron, Inc.

Although similar in size to the V-22, a 39-seat commercial tiltrotor (shown in this artist's conception) would incorporate different design features, such as a new fuselage.

the Ishida tiltwing aircraft, designed primarily for the corporate transport market, might be competitive with commercial tiltrotors on certain commercial routes. Although a 14-seat tiltwing will likely have higher seat-mile costs[50] than a 39-seat tiltrotor, it is designed to fly at least as fast and as far, use smaller landing areas, and perhaps be more economical for high-frequency service on routes with too few passengers for 39-seat tiltrotors.

Tiltrotor Service Scenarios

The Phase II team analyzed various types of service for civil tiltrotors and determined that routes of 100 to 500 miles with high levels of ground and/or air congestion at one or both ends offered the greatest potential for commercial tiltrotors. The prime markets are point-to-point trips between urban areas, including city center to city center, and commuter connections to congested hub airports. Service to small cities or uncongested hubs using 40-seat tiltrotors is not considered economically viable.

Point-to-Point Service Between Urban Areas

Travel corridors characterized by strong business travel, existing air shuttle service, and difficult ground access to major airports are leading candidates for point-to-point tiltrotor service. U.S. air travel routes with these attributes include Washington-New York-Boston, Dallas-Houston, and Los Angeles-San Francisco.

On these routes, tiltrotors would compete with larger jetliners averaging 130 seats per aircraft.[51] The value of reduced time and access costs for shorter ground trips to and from strategically located vertiports is especially critical for penetrating these airline markets, since the cost per seat for the air portion of the trip would be significantly higher for the tiltrotor than for a jetliner (see table 3-5 again).[52] Pan Am and Trump shuttles carry approximately 3.8 million passengers per year on New York-Washington and New York-Boston routes, or about three-quarters of the air travelers in these markets.

The Phase II team analyzed a hypothetical commercial tiltrotor system for the NEC and devised schedules, computed travel times, identified potential locations for vertiports, and estimated the number of passengers diverted from conventional airplanes and the number of additional flights using the airspace. The study team assumed that shorter trip times and resulting lower ground access costs would compensate for the higher operating costs and consequent ticket price for tiltrotor service and that passengers would consider fixed-wing and tiltrotor service economically equivalent. On this basis, using the Boeing Market Share Model,[53] the team calculated passenger demand based on service frequency and trip time.[54] Flight schedules and total aircraft inventory needs (based on fuel capacity, turnaround times, and other operating requirements) were estimated. Under these assumptions, the study found that commercial tiltrotors would capture 94 percent of the intra-Northeast Corridor market.

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[50] Other things being equal, larger aircraft are more economical per seat-mile than smaller aircraft. Tiltwings are projected to cost about 15 to 20 percent more to operate than an equivalent turboprop. This is similar to tiltrotor cost estimates.

[51] Boeing Commercial Airplane Group et al., Phase II Draft Final Report, op. cit., footnote 8, p. 3-92.

[52] The cost per passenger will depend, in part, on the percentage of seats that can be filled.

[53] A proprietary simulation model for fleet planning developed by Boeing Commercial Airplane Co.

[54] It is difficult to calculate market share when both cost and travel time are variables.

Table 3-5—Comparative Economic Data for Commercial Tiltrotors Operating in the Northeast Corridor

	Operating costs[a] in 1989 dollars for 230-mile trip ($ per seat-mile)		
Categories	Tiltrotor (39-seats)	Turboprop (39-seats)	B737-300 (128-seats)
Aircraft capital costs[b]	0.067	0.054	0.038
Maintenance costs	0.048	0.036	0.014
Fuel costs[c]	0.019	0.011	0.011
Total aircraft costs[d]	0.203	0.172	0.122
	Travel times[e] for 230-mile trip (hours:minutes)		
Ground travel	0:36	1:34	1:34
Airport terminal	0:30	0:45	0:45
Onboard aircraft	0:50	1:06	0:54
Total trip time	1:56	3:25	3:13
	Ground and air travel costs for 230-mile trip (per passenger)		
Taxi fare[f]	$12.80	$33.10	$33.10
Flight costs[g]	71.82	61.02	43.09
Total travel costs	84.62	94.12	76.19

[a] Assumes passengers occupy 65 percent of seats.

[b] Depreciation, financing, and insurance costs.

[c] At $0.60 per gallon.

[d] Total costs for each aircraft type, which include flight crew, passenger service, landing fee, and ground handling expenses, reflect commuter airline wage scales and service levels, which are generally less than those for major airlines.

[e] Assumes Northeast Corridor ground travel and airport conditions; turboprop and jetliner ground and airport terminal times are for major airports.

[f] Typical trips to and from Northeast Corridor airports used for turboprop and jetliner calculations; trips to and from well-situated vertiports used for tiltrotor taxi fare.

[g] Breakeven costs to airline with 65 percent of passenger seats occupied; ultimate ticket price could vary considerably.

SOURCE: Office of Technology Assessment, 1991, based on Boeing Commercial Airplane Group et al., *Civil Tiltrotor Missions and Applications Phase II: The Commercial Passenger Market*, Draft Final Report, prepared for National Aeronautics and Space Administration and Federal Aviation Administration, NASA CR 177576 (Seattle, WA: Boeing Commercial Airplane Group, February 1991).

While the Phase II NEC analysis is an important step for understanding tiltrotor effects on ATC and potential passenger demand, further scrutiny using representative market conditions is needed to provide credible support for industry or public policy decisions regarding commercial tiltrotors. The Phase II study compared tiltrotors with turboprop aircraft only and did not include the monetary value of the time saved by tiltrotor passengers in its demand analysis.[55] It is reasonable that taxi fares and airline ticket costs could be equivalent for these two types of aircraft. However, only 10 to 15 percent of airline passengers who travel between the major NEC airports do so in commuter aircraft.[56] Jetliners, the dominant mode, cost about one-third less per seat to operate than commuters along NEC routes.[57] The ground access and flight costs[58] for a tiltrotor passenger would be 11 percent higher than if the same journey were taken via major airports served by jetliners (see table 3-5 again). **A tiltrotor network would still offer significant savings in total trip time relative to jet service, but it is unclear what size passenger market tiltrotors would attract.** The jet shuttle market might be difficult to penetrate, but tiltrotors could supplement shuttle flights with new services and absorb extra traffic, if airport congestion becomes a constraint.

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[55] Estimating the value of time is admittedly difficult.

[56] OTA calculations based on *Official Airline Guide* data for April 1991.

[57] From Phase II data comparing B737-300 and generic 39-seat turboprop over a 230-mile distance in revenue passenger service.

[58] Total cost to the airline to provide the seat, not the ticket price paid by the passenger.

Revised tiltrotor demand estimates could lead to different conclusions regarding optimal aircraft size and vertiport locations. FAA is conducting independent economic and market evaluations using lower overall market projections and has a small study under way comparing commercial tiltrotors with the Pan Am and Trump shuttles, but the results are not yet publicly available.[59]

Replacing Commuter Airplanes as Airport Hub Feeders

Air service from small cities to congested or slot-constrained hub airports is another potential market for commercial tiltrotors. Commuter turboprop airplanes provide most of this feeder service, and replacing some of them with similarly sized tiltrotors could free up valuable landing slots for more productive, long-haul aircraft while still providing vital air connections for small communities. The potential passenger capacity gains for NEC airports are substantial. At Boston, for example, commuter airlines use 30 percent of the landing slots but carry only 5 percent of the airport's passengers.[60] Since tiltrotors cost more to operate and offer no significant time savings over commuter turboprop airplanes if both fly from conventional airports, the economic viability of tiltrotors in this market depends on balancing higher tiltrotor costs with the increased revenues and benefits from runway slots that could be used by more people in larger aircraft. Presently, there is no public policy encouraging efficient use of runway slots or enabling airlines to "capture" the benefits of congestion relief.

Maintaining (and increasing) market share is important to airlines. Established air carriers and their commuter airline partners have little incentive to free up runway slots if other airlines get to use them. With the exception of four airports—Chicago O'Hare, New York Kennedy, New York LaGuardia, and Washington National—landing and takeoff slots are first come/first serve for any aircraft operator. At the four "slot-controlled" airports, landing and takeoff quotas have been established by FAA for three user classes—air carriers, commuters, and general aviation. Federal regulations[61] prohibit the transfer of slots between user classes (e.g., an air carrier cannot use a commuter slot). Moreover, air carriers would not always be able to take advantage of a commuter slot even if one opened up, since at many airports turboprop aircraft use runways too short for jetliners.[62]

Two-thirds of airline delays occur during bad weather,[63] when short runways are usually not used. With current technology and procedures, most airports can safely operate one or two runways only, when atmospheric conditions, such as low clouds, impair pilot and tower controller visibility. This reduces by 50 percent or more the number of aircraft that can takeoff and land relative to clear-weather capacity. Under these circumstances, commuters, private aircraft, and jetliners alike must use the same runways, further complicating the already congested traffic flow. Tiltrotor service could clearly increase capacity at some busy airports, such as New York's LaGuardia, that do not have separate runways available for commuter turboprops.

The Phase II study investigated the economics of replacing some hub feed commuter flights to NEC airports with tiltrotor service and calculated the number of slots freed and the required cross-subsidy per slot to cover the tiltrotor's higher costs. The methodology for this analysis was to calculate the cost difference to provide the same number of seats annually by 39-seat tiltrotors and 31-seat turboprops.[64] The slot revenue required to support tiltrotor service based on these calculations[65] ranged from over $100 per day per runway slot for Washington, DC, to virtually nothing for Philadelphia.[66]

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[59] Michael Zywokarte, NYMA, Inc., personal communication, July 22, 1991.

[60] Massachusetts Port Authority, "Massport's Program for Airport Capacity Efficiency," unpublished report, Dec. 11, 1987.

[61] 14 CFR 93, Subpart K.

[62] The Federal Aviation Administration has proposed amending slot rules to permit regional jets (as large as 110 seats) to use a limited number of commuter turboprop slots at Chicago O'Hare. See 56 *Federal Register* 21404 (May 8, 1991) for further details.

[63] U.S. Department of Transportation, Federal Aviation Administration, *1990-91 Aviation System Capacity Plan*, DOT/FAA/SC-90-1 (Washington, DC: September 1990), p. 1-11.

[64] The 31-seat generic turboprop in the Phase II database approximates the 30-seat overall average for the Northeast Corridor markets analyzed.

[65] Assumes that tiltrotor purchase price is 50 percent higher than an equivalent turboprop, or $300,000 per seat, and that tiltrotors would replace all turboprops flying the busiest (top 50 percent) routes to the hub airport.

A limitation of this Phase II analysis is that it does not address the economics of replacing each turboprop flight with a tiltrotor. For example, in the Boston commuter market, where average aircraft size is 24 seats, small communities would lose 38 percent of their flights to Logan Airport under the equivalent seat scenario. For Boston, the cross-subsidy would have to be at least seven times higher than the figures published in the Phase II report if equal frequency service is to be provided by 39-seat tiltrotors.[67] Using tiltrotors closer to the size of the aircraft that they replace would be somewhat better economically if equivalent schedules are to be maintained. For the Washington, DC, market, where commuter flights average 39 seats, it would cost $470 extra to replace a turboprop round trip with tiltrotor service (thereby freeing one slot).[68] (The landing fee for a 150-seat aircraft at Washington National Airport is about one-third[69] this amount.)

Domestic and Worldwide Potential Market

Three-quarters of all scheduled airline flights worldwide are for travel less than 500 miles, making them potential candidates for replacement by tiltrotors. Using *Official Airline Guide* schedules and Boeing Commercial Airplane Co. forecast data, the Phase II study predicted potential demand for tiltrotor aircraft by examining the traffic characteristics of the busiest routes, considering only those routes where tiltrotor economics could be favorable. City pairs with lower density traffic, less ground congestion, or routes longer than 300 miles were de-emphasized, and small markets, hub feeder flights, and airlines offering few flights per week were excluded. Other economic assumptions used in the NEC analysis were applied in the global market assessment. The Phase II study identified 220 candidate city pairs that could use over 2,600 commercial 40-seat tiltrotors by the end of the decade if a suitable infrastructure were in place (see table 3-6). Approximately one-half of this potential demand lies outside the United States. Further analysis is necessary to account for direct economic competition between jetliners and tiltrotors, since only turboprops were the reference base. Jets provide about 45 percent of the passenger capacity for trips under 500 miles.

For the year 2000, Ishida projects a market for about 750 high-speed VTOL aircraft, and Eurofar sees demand for 30-seat commercial tiltrotors,[70] with both groups anticipating a similar 50-50 split between the United States and the rest of the world in demand for their high-speed VTOL aircraft.[71] These estimates indicate that U.S. market conditions (including infrastructure policy decisions) could determine tiltrotor (and other high-speed VTOL) characteristics. If the magnitude of worldwide commercial tiltrotor demand

Table 3-6—Market Potential for 40-Seat Commercial Tiltrotor in Year 2000

Region	City pairs	Number of aircraft
North America[a]	117	1,268
Europe	57	615
Japan	26	501
Oceania[b]	20	239
Total	**220**	**2,623**

[a] Seven areas: 1) Northeast Corridor; 2) Southeast, based in Atlanta; 3) Midwest, based in Chicago; 4) South-central, based in Dallas-Fort Worth; 5) Southwest, centered in San Francisco, Los Angeles, San Diego, and Phoenix; 6) Northwest, based in Seattle; and 7) Hawaiian Islands.

[b] Western Pacific Rim countries, excluding Japan.

SOURCE: Boeing Commercial Airplane Group et al., *Civil Tiltrotor Missions and Applications Phase II: The Commercial Passenger Market*, Summary, prepared for National Aeronautics and Space Administration and Federal Aviation Administration, NASA CR 177576 (Seattle, WA: Boeing Commercial Airplane Group, February 1991).

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[66] Tiltrotors compare so favorably with turboprops in the Philadelphia market because the average trip distance is small, around 124 miles. Tiltrotors become more economical than conventional airplanes for trip distances under 100 miles or so. However, helicopters perform better than tiltrotors if distances are reduced further.

[67] This estimate is based on the cost difference, accounting for different passenger load factors, between flying 39-seat tiltrotors and 31-seat turboprops on the Boston routes. Data source is the Phase II report. The cost difference would be substantially greater between 39-seat tiltrotors and the 24-seat average aircraft actually flown in the Boston market.

[68] The Phase II study, by using the 31-seat turboprop as the reference base for the Washington, DC, market analysis, underestimates the tiltrotor cost difference, since the smaller aircraft would be more expensive to use on Washington, DC, routes than would 39-seat turboprops.

[69] The landing fee for air carriers at Washington National is $1.04 per 1,000 pounds of landing weight, or around $160 for a B-727.

[70] We assume that all these markets overlap, and the figures are therefore not additive.

[71] Kocurek, op. cit., footnote 22; and Joseph M. Del Balzo, executive director for System Development, Federal Aviation Administration, testimony at hearings, in House Committee on Science, Space, and Technology, op. cit., footnote 40, p. 157.

holds true, the export value of U.S.-manufactured tiltrotors could exceed $15 billion in 2000.[72]

Institutional Framework

Congressional and other public interest in tiltrotors has focused primarily on the vehicle technology and its military role. Whether potential benefits of proposed tiltrotor service, such as congestion relief, are realized will depend on the institutional framework and the air and ground infrastructure within which tiltrotor must be developed and operated. Marketing skills and political and industrial coalitions will be essential for getting the technology out of the workshop. A host of challenges, many of them nontechnical, face future tiltrotor intercity systems, including: community acceptance of facilities and operations; properly situated terminals with adequate ground connections; suitable ATC equipment and procedures; people and organizations willing and able to plan, design, build, operate, maintain, and manage the system; a regulatory framework to ensure that the system is developed and run in a safe, environmentally acceptable, and economically fair manner; and available financing to support the system (see table 3-7).

Tiltrotor Safety Oversight

FAA, which has regulatory authority for all aspects of civil aviation safety, would be responsible for certifying tiltrotor vehicles, operations, procedures, personnel, and landing facilities. Because it has worked closely with DOD to collect data from the V-22 flight test program, FAA is well positioned to provide safety certification services if industry proceeds with a civil tiltrotor program. FAA's Rotorcraft Directorate in Fort Worth, Texas, has developed airworthiness standards[73] that apply to other powered-lift vehicles as well. FAA methodology for developing helicopter en route and terminal airspace procedures is applicable to tiltrotor, and some existing helicopter routes might be suitable for tiltrotors. A vertiport design guide to aid local planners has recently been released by FAA.[74] If put into common carrier service, tiltrotors will be subject to the same or equivalent operating regulations as larger airliners.[75]

While additional flight testing and analyses are needed to establish specific requirements for tiltrotors (e.g., pilot training, cockpit instrumentation, maintenance standards), **neither the tiltrotor design nor FAA's regulatory framework should significantly impede the certification of a civil tiltrotor.** However, some tiltrotor operations and procedures cannot be certified until appropriate ATC technologies are developed and approved and actual flight test aircraft are available.

Environmental Issues and Community Acceptance

The feasibility of establishing vertiports depends on the balance of environmental concerns and perceptions, the state of local transportation systems, and the potential for economic development. Aircraft noise is a serious problem for airport operators and airlines, and is the leading environmental issue for tiltrotor. Community groups fighting to restrict airport operations because of noise concerns have limited airport development across the country. Interviews conducted with public officials in 13 U.S. cities indicated that vertiports could be located and tiltrotors operated in their urban areas if noise levels are as low as projected.[76] New public heliports have opened in recent years or are being built in Indianapolis, Manhattan, Portland (Oregon), and Dallas,[77] but helicopter operations are not welcome in most communities, and few scheduled helicopter airlines have ever been profitable (see box 3-C).

While the intensity of sounds can be measured precisely, determining what constitutes objectionable

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[72] Assuming a $300,000 per-seat purchase price.

[73] U.S. Department of Transportation, Federal Aviation Administration, "Interim Airworthiness Criteria: Powered-Lift Transport Category Aircraft," unpublished report, July 1988.

[74] U.S. Department of Transportation, Federal Aviation Administration, *Vertiport Design*, Advisory Circular 150/5390-3 (Washington, DC: May 31, 1991).

[75] 14 CFR 121 or comparable regulations would apply if tiltrotors have more than 30 passenger-seats.

[76] Robert L. Neir, market research manager, Boeing Commercial Airplane Group, personal communication, Feb. 27, 1991.

[77] Zywokarte, op. cit., footnote 42.

Table 3-7—Tiltrotor System Issues

Component	Issues	Comments
Tiltrotor aircraft	V-22 program status; need for a civil demonstration program; commercial market size.	Administration has attempted to end the V-22 in fiscal years 1990 and 1991; civil demonstration program proposed in the NASA/FAA Phase II study.
Vertiport	Federal airport capital grant policy for vertiports is unclear; sites that are acceptable to communities and are operationally suitable depend in part on new technologies and flight procedures.	Waterfront, industrial, underused small airports, and nonurban interstate sites appear plausible; residential and central business district locations doubtful; multiple-use facilities could help limit development costs for vertiport portion.
ATC system	Appropriate technology, procedures, and manpower needed to gain benefits of tiltrotor flight capabilities. Large increase in the number of daily en route flights possible.	Rotorcraft have never been well integrated into the airspace system; no public heliport in the United States now has precision instrument landing capabilities essential for scheduled passenger operations. En route operations by tiltrotors are no different than those by conventional aircraft, and FAA has programs under way to enhance the capabililties of en route airspace.
Regulatory oversight	Cockpit design and pilot training; noise standards for tiltrotor and vertiports.	V-22 flight test data are being analyzed by FAA; airworthiness criteria for tiltrotor-type aircraft are published (in interim form); vertiport planning guidelines are available; airspace procedures are being studied in simulators.
Potential operators	Major airlines have not embraced tiltrotor. Are potential tiltrotor system benefits realizable for an existing or entrepreneur airline?	Lack of aircraft and infrastructure has dampened airline interest; airlines will not voluntarily free up airport capacity for competitors; scheduled passenger helicopter service, in some respects comparable to tiltrotor, is virtually nonexistent in the United States.
Local communities	Noise, safety of overflights, and potential increases in surface traffic are key community concerns.	With appropriate airspace procedures, vertiports and their operations could be isolated from residential areas; some planning analyses are under way (e.g., FAA vertiport studies).
Passengers	Would potential passengers recognize cost and service benefits of tiltrotors?	Safety and service levels at least comparable to large commuter operations required; total direct ground and air costs to passengers could be less than current air options in certain markets. How do travelers value ground access time and cost?
Financiers and investors	What assurances are needed for non-Federal investors in tiltrotor technology and what is the Federal role?	Public and private investment in the United States limited primarily to planning and design studies to date; new heliports are being designed to vertiport standards; no commitment to develop commercial tiltrotor in the United States.

KEY: NASA = National Aeronautics and Space Administration; FAA = Federal Aviation Administration; ATC = air traffic control.

SOURCE: Office of Technology Assessment, 1991.

noise is more subjective. FAA sets noise standards for aircraft designs, commonly referred to as Stage 1, 2, and 3 rules,[78] and for airport planning.[79] While differences in local conditions and jurisdictional factors have made establishing a more definitive Federal standard for airport noise difficult, Stage 1 aircraft are already banned, and all Stage 2 aircraft are prohibited after December 31, 2000.[80] Rotorcraft are not presently covered by these "stage" rules, but industry proponents claim a civil tiltrotor would be able to meet Stage 3 requirements.

Although civil tiltrotors might be less noisy on commercial flight paths than helicopters and most fixed-

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[78] 14 CFR 36.

[79] 14 CFR 150.

[80] *Congressional Record*, Oct. 16, 1990, p. 12535.

Box 3-C—Current Helicopter System Issues

Since helicopters and tiltrotors perform comparably at or near landing facilities, a look at helicopter airline operations might illuminate potential tiltrotor system obstacles. A great many helicopters, trained pilots, and public and private heliports exist in the United States, and helicopters are used extensively in situations where no other aircraft could operate—emergency medical services, police operations, search and rescue missions, and offshore oil rig support, to name a few. Scheduled helicopter service from Chicago, New York, and Los Angeles airports was subsidized by the Federal Government from 1954 through 1966, and each of the helicopter airlines operating during those years went out of business by the late 1970s. During the past decade, a few helicopter airlines established interline agreements with major airlines, which helped defray the cost of these connecting flights for their passengers. None of these airlines is currently operating.[1] Although operating costs are much higher than those of airplanes, economics alone has not kept helicopter passenger service on the ground.

Lack of a "helicopter friendly" infrastructure is the main complaint of rotorcraft operators. Few public heliports exist, and none are equipped with precision landing guidance systems that are essential for all-weather scheduled operations. When helicopters use conventional airports, air traffic controllers usually direct them along airplane flight paths (which are fatal to any profit margin the helicopter had), even though helicopter-specific routes are often available. Air traffic controllers are inherently conservative and are most secure with airplane procedures. Moreover, during busy periods, controllers may be able to monitor only fixed-wing routes safely.[2]

Noise, on the ground and in the cabin, has weakened public acceptance of helicopter service. However, some noise problems are due to flight paths dictated by air traffic control (ATC), and current technological know-how could reduce noise (interior and exterior) and vibrations and improve ATC capabilities. Rotorcraft manufacturers and the Federal Aviation Administration, with most of its resources and expertise devoted to fixed-wing aircraft, have not strongly promoted passenger helicopter service.

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[1] **HubExpress, one of the few scheduled helicopter services in the United States, recently went out of business.**

[2] **Joel Hicks, director for Safety, Technology, and Training, National Air Traffic Controllers Association, personal communication, Mar. 22, 1991.**

wing aircraft, they may not be quiet enough to satisfy those communities where vertiports are most likely to be located to capture the largest possible market share. FAA actions to reroute aircraft over New Jersey caused an uproar from communities that previously had few overflights, even though average sound intensity from these flights was less than that from normal conversational tones. Moreover, most communities that might accept tiltrotor vertiports would turn them down if louder helicopter operations were permitted.[81] On the other hand, vertiport operators would probably welcome the additional revenue from helicopter flights. Technically, helicopters could be designed and operated to be less noisy than is common now. Presently, there are no Federal noise standards specifically for heliports or vertiports. Airport noise compatibility planning guidelines (14 CFR 150) are now used for heliports.[82]

The environmental impact of building (as opposed to operating) a vertiport should be relatively minor, especially compared with airport and other transportation infrastructure construction, owing to minimal land requirements (up to 5 acres). Also, the air quality impact of tiltrotor engine emissions should be relatively small. In the Los Angeles basin, aircraft exhaust and fueling emissions from all aviation operations contribute about 1 percent of the total volatile organic compounds. FAA and the Environmental Protection Agency (EPA) are addressing these air quality issues by requiring that new jet engines reduce organic compounds emissions by 60 to 90 percent. EPA is considering regulations requiring vapor recovery systems for aircraft fueling,[83] and civil tiltrotors would be required to meet these standards.

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[81] Boeing Commercial Airplane Group et al., Phase II Summary, op. cit., footnote 8, p. 11.

[82] The definition of "airport" in 14 CFR 150.7 specifically excluded heliports until 1989.

Role of the Airlines

Commercial tiltrotor passenger service in the United States, if practical, will likely be controlled by major air carriers rather than by new tiltrotor airlines. Potential tiltrotor routes are now dominated by jetliner shuttle flights or commuter airlines associated with the major carriers. While tiltrotors could offer a way to avoid the shortage of airport gates and runway slots that hinder access into the largest intercity air travel markets, high purchase and operating costs and necessary technical sophistication could put tiltrotors out of the reach of financially strapped startup airlines. Moreover, the formidable marketing power of major airlines—extensive route networks, frequent flyer programs, travel agent commissions, and computer reservation and ticket pricing databases—has become essential in competing for air travelers. Most commuter airlines now operate under the name of a major carrier, who often dictates the smaller airline's schedules, airport gates, and advertising.

U.S. airlines have expressed little interest in commercial tiltrotors. Beset with financial losses in recent years, a number of airlines concentrate on day-to-day survival. Tiltrotor aircraft, which will cost more to purchase and operate than conventional airplanes and will require new infrastructure, turn few heads in airline management. Before an airline will consider placing orders for a commercial tiltrotor, it must be convinced that the aircraft is operationally reliable and economically viable. Data from military production and operation of the V-22 and a civil tiltrotor demonstration program would get airlines' attention regarding tiltrotor technical performance. Proven community acceptance and a public commitment to install the infrastructure would also be crucial.

Establishing that commercial tiltrotor has more than a niche market potential is another matter. Tiltrotor costs and public policies regarding airport congestion combine to offer few incentives for airlines to introduce tiltrotor service. The potential benefits of commercial tiltrotors would not go to an airline's balance sheet, but would instead go mostly to the tiltrotor passengers, who would get quicker and easier trips. The general public would also receive expanded aviation system capacity for relatively little infrastructure investment. The tiltrotor's advantage to individual airlines is unclear. Data from the Phase II report indicate that beating the profitability of jetliner shuttles, which in most cases can switch to larger airplanes as demand grows, is questionable (see table 3-5 again). Furthermore, a recent analysis indicates that the primary air carriers in the NEC lost $11 million in operations there in 1990.[84] The need and value of freed runway slots has not been demonstrated, and there is no policy to ensure that an airline could take advantage of the runway slots it opens through tiltrotor service.

Financing

The Federal Government has spent over $2.5 billion for XV-15 and V-22 development programs,[85] and private industry has invested another $200 million to $300 million of its discretionary funds on tiltrotor technology.[86] Around $1 billion to $1.5 billion more will be necessary for U.S. industry to develop, certify, and produce a commercial tiltrotor,[87] and like other U.S. commercial aircraft programs, most of this funding would have to come from private sources. So far, private industry has not pledged to develop a commercial tiltrotor.

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[83] Nicholas P. Krull, Office of Environment and Energy, Federal Aviation Administration, personal communication, July 31, 1990.

[84] John P. O'Donnell, Volpe National Transportation Systems Center, personal communication, June 28, 1991.

[85] Boeing Commercial Airplane Group et al., Phase II Summary, op. cit., footnote 8, p. 4.

[86] Federal Aviation Administration, Research, Engineering and Development Advisory Committee, Tiltrotor Technology Subcommittee, *Report* (Washington, DC: June 26, 1990), p. 12.

[87] Philip C. Norwine, vice president, Commercial Market Development, Bell Helicopter Textron, personal communication, Feb. 6, 1991.

The five European governments that sponsor Eurofar have spent $30 million[88] on commercial tiltrotor studies during the past 3 years and are developing a technology base and considering building a tiltrotor demonstrator over the next 5 years. The figures for the TW-68 tiltwing program, financed to date only by Ishida Corporation, are not publicly available. However, Ishida officials claim funding is assured through prototype flight testing.

Without continued production of the V-22 or additional public funding to develop and demonstrate civil tiltrotor technology, a U.S. company will not build a commercial tiltrotor this decade. A recurring question in debates on Federal participation in civil tiltrotor programs is "if the technology is such a good idea, why doesn't U.S. industry fund it without public support." One group that looked into this question concluded that the reasons are: 1) a lack of long-term capital support in the United States; 2) insufficient or nonexisting infrastructure; and 3) no confidence or commitment from potential operators without operational test data.[89]

The Phase II study recommends creating a 4-year program, costing roughly $250 million, to develop further the tiltrotor vehicle and infrastructure technologies and to assess the feasibility and benefits of a commercial tiltrotor system.[90] The centerpiece of the program is a series of operational demonstrations using XV-15 and V-22 tiltrotors. Commercial product development or production is not proposed.

Federal support for VTOL infrastructure is continuing. Federal Airport Improvement Program grants are available for planning and building landing facilities that relieve traffic from air carrier airports (as would be expected at vertiports). FAA has provided about $3 million to local authorities for vertiport planning studies, and it is expected that construction grants will be available for vertiports. However, FAA policy is not yet clear on vertiport construction. Expected Federal capital grants for the first public heliport designed to accommodate 40,000-pound tiltrotors were tied up within FAA because no manufacturer has committed to producing commercial tiltrotors, and the need for vertiports has not yet been (officially) established.[91] However, a portion of the earlier assigned Airport Improvement Program funds was awarded in fiscal year 1991, and FAA plans to issue additional funds in fiscal years 1992 and 1993 for the Dallas Convention Center heliport.[92]

Findings and Conclusions

For tiltrotors to succeed commercially, the congestion and delays that have increasingly plagued roads and airports during the past decade must continue to grow. Airlines and their customers will demand tiltrotors (which cost more to build and operate than competing fixed-wing aircraft) only if the expense of ground and air congestion becomes too severe. While most aviation forecasts project that passenger demand will grow faster than airport capacity, future congestion levels are difficult to assess. FAA predicts most increases in aircraft flights will occur at hub airports, where airline scheduling strategies rather than passenger demand determine how crowded the runways and ramps become. Moreover, the same airline philosophies, community concerns about noise, and public policies that have hampered other means of overcoming air travel delays will affect tiltrotor use.

Although further research and FAA certification approval would be needed, the technical feasibility of safely carrying passengers with tiltrotors is not seriously in doubt, and tiltrotors could offer one way to avoid clogged highways and overburdened runways and might help expand the capacity of busy hub airports. High-density urban-to-urban routes and feeder service to congested hubs are the most promising markets for commercial tiltrotors. A tiltrotor network would offer significant time savings relative to jet service for trips under 500 miles, but it is unclear how far tiltrotors would penetrate into the markets served by the generally more cost-effective jet shuttles. Without similar time savings over less expensive commuter feeder flights from small communities, tiltrotor service would be economically feasible only if subsidized. Replacing a typical turboprop roundtrip feeder flight with 39-seat tiltrotor service would cost about $500 extra,[93] but would free one "slot" that could be used by a larger and more productive aircraft.[94] This amounts to only a few dollars each for passengers on a 300-seat jetliner, but is more than the typical landing fee charged to the same aircraft. With the exception of flights at the four "slot-controlled" airports, airlines have little incentive to free runway slots, since this would be equally helpful to competitors. Furthermore, Federal regulations[95] prohibit the transfer of commuter slots to large jetliner flights.

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[88] Norwine, op. cit., footnote 10.

[89] Federal Aviation Administration, op. cit., footnote 86, p. 6.

[90] John Zuk, chief, Civil Technology Office, NASA Ames Research Center, personal communication, Apr. 11, 1991.

[91] Chris Basham, vice president, Charles Willis & Associates, Inc., personal communication, May 20, 1991.

[92] Ibid.

Individual airlines have little interest in pushing for commercial tiltrotor development. While tiltrotor passengers and the aviation system as a whole might benefit from tiltrotor service, airlines see mostly risks and no additional profits over the status quo. Thus, the market for commercial tiltrotors is speculative, even if a suitable infrastructure were available and airlines and local communities accepted tiltrotor operations, both of which are far from guaranteed.

The time savings of tiltrotor service hinges on well-situated vertiports. Since tiltrotors do not need runways, 5-acre or smaller vertiports might be built at accessible locations where conventional airports would be environmentally unfeasible or prohibitively expensive. But aircraft noise is a serious problem for airport operators and airlines, and is the leading obstacle to community acceptance for tiltrotor. On the other hand, tiltrotor engineers predict that less noise will reach the ground from tiltrotors than from conventional airplanes or helicopters.

The capabilities of airside infrastructure are also essential to tiltrotor success. Real estate height restrictions and noise will be kept to a minimum if tiltrotors fly steep angles into and out of urban vertiports, but this requires advanced guidance technology and procedures. If tiltrotors make inroads into the busiest intercity travel corridors, they will increase substantially the number of daily flights in the ATC system. Three to five tiltrotors would be needed to carry the passengers served by each jetliner. Although tiltrotors might fly in new or less crowded corridors, compatible ATC capabilities must be ensured lest tiltrotors overcome one form of congestion just to create another.

To enhance public acceptance of tiltrotor operations, technologies need to be perfected that improve rotor designs to reduce noise; ensure operating safety through well-tested cockpit instruments, controls, displays, and pilot training procedures; and enable steep flight paths to and from vertiports. Each of these research, development, and demonstration efforts is equally valuable to most civil VTOL aircraft.

Given these uncertainties, private industry and investors have not committed the substantial funds needed to develop a commercial tiltrotor. The Federal Government has spent over $2.5 billion for XV-15 and V-22 development programs,[96] and private industry has invested another $200 million to $300 million on military tiltrotor technology.[97] U.S. industry would have to inject around $1 billion to $1.5 billion more to produce a commercial tiltrotor.[98]

Without Federal management and financial support for infrastructure and precommercial tiltrotor technology development and testing, U.S. industry will not produce commercial tiltrotors in this decade. If the V-22 program is continued, enough engineering and operational experience might be gained for industry and investors to make firm decisions, either pro or con, regarding commercial tiltrotor production. Industry observers believe that the V-22 design is unacceptable for most commercial transport applications, due to economic and civil performance penalties inherent in meeting military requirements. However, some V-22 structural and propulsion designs and components might be directly transferable to a commercial tiltrotor. Because it has worked closely with DOD to collect data from the V-22 flight test program, FAA is well positioned to certify a V-22 for noncommercial, civil operations by 1995 if a sponsor requests it.

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[93] The average Northeast Corridor commuter route (in the Phase II market base) is 172 miles one way and served by 30-seat turboprop aircraft.

[94] The extra tiltrotor "cost per-slot vacated" could be reduced significantly if fewer tiltrotor flights (but equivalent weekly passenger capacity) were used. However, passengers generally consider lower frequencies as a decline in service quality.

[95] 14 CFR 93, Subpart K.

[96] Boeing Commercial Airplane Group et al., Phase II Summary, op. cit., footnote 8, p. 4.

[97] Federal Aviation Administration, op. cit., footnote 86, p. 12.

[98] Norwine, op. cit., footnote 87.

The national benefits and industrial competitiveness implications stemming from commercial tiltrotor need further study, especially if significant Federal support for a U.S.-produced vehicle or the accelerated development of tiltrotor infrastructure is considered. Currently, the United States has about a 5-year development lead worldwide in tiltrotor technology, and with over one-half the potential demand for commercial tiltrotors overseas, this suggests a possibly favorable trade position. However, there is foreign interest in developing high-speed VTOL aircraft and producing commercial vehicles. Regardless of Federal and industry decisions for tiltrotor, the Ishida Group of Japan will likely sell the first high-speed VTOL aircraft in the civil market. However, the Ishida tiltwing will be designed, developed, and produced in the United States.

If tiltrotor service can overcome air and ground congestion, and even reduce delays at busy airports, it could enhance domestic productivity. But these gains must be balanced with the changed noise patterns, higher energy consumption, and increased air traffic that would arise from tiltrotor operations.

CHAPTER 4

Magnetic Levitation and Related Systems

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CHAPTER 4

Magnetic Levitation and Related Systems

Twin goals—to relieve air and ground traffic congestion and to be technologically competitive in transportation—have prompted considerable interest in the United States in high-speed ground transportation alternatives. The ridership levels enjoyed by high-speed rail systems[1] in France and Japan and in some high-speed rail corridors in other countries demonstrate the feasibility of high-speed rail technology and arouse interest in a guided ground transportation technology that is potentially even faster—magnetically levitated (maglev) vehicles. High-speed rail is an off-the-shelf technology, and could be operated in the United States over some existing rail right-of-way, if the track were upgraded appropriately. Maglev prototypes have been tested extensively, but to operate, a maglev system would require new rights-of-way and construction of a new and different guideway.

The uncertainties about ridership, costs, infrastructure investment, and some technical issues that accompany any new transportation technology make it hard to assure the commercial success of either high-speed rail or maglev in this country. In fact, efforts so far to finance such new systems in the United States from private sources have not succeeded. In addition, only a sketchy regulatory framework currently exists here for these technologies. Moreover, it is unclear whether their environmental effects—principally noise and electromagnetic fields—are acceptable to the public, or which corridors have sufficient ridership potential and feasible construction costs. At this point, it is safe to say that intercity maglev will require some governmental support for system development, testing, and construction.

Despite these unanswered questions, supporters of intercity maglev and high-speed rail systems claim a number of benefits: superior safety, economic development near stations along the corridor, low air pollution, technology leadership and export potential from developing or implementing an advanced transportation system, independence from petroleum-based fuels, improved transport energy efficiency, increased tourism and employment, and reduced (airline competitive) travel time and congestion of other transportation modes. In addition to transporting passengers, both could carry low-density freight during offpeak hours, and their rights-of-way could be used for other purposes, such as fiber optic cables and other communications links. Obstacles to both maglev and high-speed rail center around right-of-way acquisition, infrastructure costs, and an uncertain market.

High-speed rail technologies capable of speeds greater than 125 to 150 miles per hour (mph) have been commercially introduced on a wide scale in France, Japan, and, most recently, Germany. Generally considered for the same intercity corridors as maglev, such systems have received serious consideration in the United States in California, Texas, and Florida. A number of other areas have either completed studies or are now evaluating potential high-speed service.

Maglev concepts can include one or many vehicles, but all include levitating and propelling a mass transportation vehicle or vehicles by magnetic forces. Maglev systems are potentially quiet, efficient transportation alternatives that could make the Nation less dependent on petroleum, the source of 97 percent of U.S. transportation energy. A number of designs and applications have been developed or proposed for maglev, ranging from low-speed people movers to intercity trains traveling 300+ mph. Although maglev has not yet been used for high-speed commercial service, systems are under evaluation for several applications worldwide. For example, Transrapid technology developed in Germany is being considered for corridor and feeder routes in the United States and has been examined as a potential option for the Soviet Union, Saudi Arabia, and Canada. Opinion among high-speed ground transportation experts in this country is sharply divided on whether to develop U.S.-based technology or adapt existing foreign technologies to U.S. conditions. Table 4-1 describes the status of various intercity corridor projects, both maglev and high-speed rail, in the United States.

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[1] These are steel wheel-on-rail systems that travel at sustained speeds in excess of 125 miles per hour.

This chapter discusses various technologies and issues for maglev, including research and development (R&D), estimated performance characteristics, environmental impacts, costs, benefits, and the institutional framework surrounding maglev, including safety, regulation, and financing. Comparisons and contrasts for high-speed rail are provided in many instances, since it is an option that is available now. **At issue are the appropriate Federal roles in developing U.S.-based technology, adapting existing foreign systems to U.S. applications, developing safety standards, and funding intercity corridors and demonstration projects.**

System Concepts

Maglev designs, which run the gamut from slow-speed people movers (50 mph or less) to high-speed (300+ mph) passenger vehicles, have been proposed for intracity as well as intercity applications. Maglev vehicles, which could consist of one to any number of passenger cars, are supported, guided, and propelled by electromagnetic or electrodynamic forces over a dedicated (usually elevated) guideway (see figure 4-1). Maglev systems generally fall into two categories, characterized by how the vehicle is suspended. The suspension technologies for proposed and existing maglev designs include electromagnetic suspension (EMS), which the high-speed German Transrapid uses, and electrodynamic suspension (EDS), used by the Japanese National Railways (JR) system (see box 4-A). Alternative designs have been proposed that incorporate automatic banking features to improve passenger comfort through curves while still maintaining high speeds. Maglev concepts considered in this chapter are limited to multisection vehicles operating on trunk lines. Other concepts, such as single-vehicle operations serving offline stations, are described in box 4-B.

Although top speeds of 300 mph would dwarf the capabilities of any existing ground transportation system, additional time savings diminish over a given distance for successive speed increases. Station stop times at intermediate points, reduced speed through curves, and the additional time required for acceleration and deceleration also lower average trip speed and increase overall travel time. Thus, a straight route without unnecessary stops will enhance ridership prospects for maglev. Proposed station sites include city centers, airports, suburbs, and passenger terminals for other modes. Almost all maglev concepts currently envision just one system operator using the infrastructure.

Other potential advantages of maglev include enormous passenger capacity and vehicle consist[2] flexibility. Since maglev vehicles in some concepts could depart at intervals of 1 minute or less (current high-speed rail systems operate at 3- to 4-minute intervals), as many as 10,000 to 20,000 passengers per hour could be moved with 200-passenger vehicles. Because most maglev systems do not have onboard propulsion units (the power is in the guideway), small passenger vehicles might be feasible, which would allow direct, economical, point-to-point service without intermediate stops. For commuter and people mover applications, maglev offers no fundamental advantage over conventional rail technology, although it may produce less noise, be less costly to maintain, and be able to accelerate faster. Short, slower speed maglev routes have been proposed more for reasons of technology demonstration and possible economic development than for any dramatic improvements over existing technology options.

For passenger comfort, both the Transrapid and JR systems would require a route with little horizontal or vertical curvature to achieve revenue speeds as high as those reached in tests. Even high-speed rail systems, such as the French TGV, need a straight right-of-way in order to achieve top revenue speeds (presently 186 mph). Since a straight right-of-way is not feasible in many of the U.S. intercity corridors most in need of additional high-speed capacity, some designers have proposed a maglev system capable of high speeds around curves, through a vehicle that can tilt, a banking guideway, or both.

Tilting technology is not new; in fact, tilting trains are currently in use in Italy, Sweden, and Spain that

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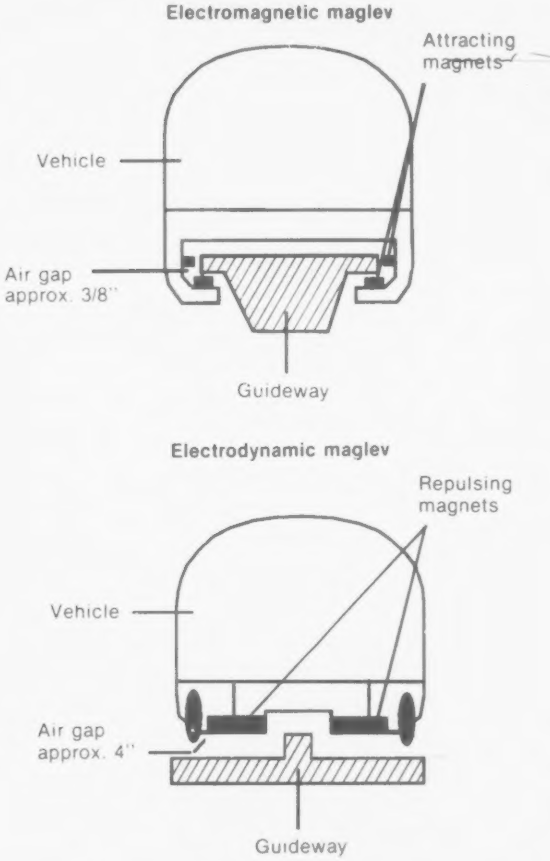
[2] Consist refers to the order and number of cars in a train.

Table 4-1—Maglev and High-Speed Rail Corridors Under Consideration

Corridor	Route length	Technology	Overseeing authority	Status and cost
Orlando Airport-International Drive	13.5 miles	Maglev (Transrapid)	Originally the Florida High Speed Rail Transportation Commission (State legislature commissioned), now the Florida Department of Transportation's Office of High Speed Transportation	The system was certified by the State of Florida in June 1991 with the stipulation that construction begin within 3 years and operation within 5 years. Preliminary estimates place the cost at around $500 million. The project is a privately funded venture with Japanese, German, and U.S. investors financing the project.
Tampa-Orlando-Miami	325 miles	Most likely steel-wheel high-speed rail	Florida High Speed Rail Transportation Commission	Originally supposed to be a public-private venture, the project has been put on hold due to lack of private investors. Originally the State investment was expected to total $6.8 billion, but that is likely to increase dramatically without private funds.
Houston-Dallas-Austin-San Antonio	610 miles	Steel-wheel high-speed rail (TGV)	Texas High Speed Rail Authority (authorized by State legislature)	A franchise was awarded in May 1991 to a consortium headed by Morrison-Knudsen, which will build a TGV system. Southwest Airlines opposed consideration of public financial support for this system and took steps to ensure that State law prohibiting such funding was followed. Costs for the project are estimated to be $5.8 billion. Some public-private financial cooperation is expected.
Anaheim-Las Vegas	265 miles	Maglev (Transrapid)	California-Nevada Super Speed Ground Transportation Commission	In the summer of 1990, the Bechtel Corp. was awarded a franchise to build a system. Bechtel began an environmental impact study, planning for system construction in 1993. It recently pushed back that date 5 years. The project, originally thought to be completely privately funded, was estimated to cost $5.1 billion. Bechtel's announced delay has been caused by difficulty in lining up private investors.
Pittsburgh	Possible 19-mile demonstration project	Maglev (Transrapid)	Maglev, Inc. (consortium)	The group released a feasibility study recommending the building of a demonstration project connecting downtown Pittsburgh with the airport. Later projects would connect Pittsburgh with outlying communities in a three-State area. The group envisions starting construction of the demonstration project in 1997, but funding concerns have yet to be resolved.

SOURCE: Office of Technology Assessment, 1991.

Figure 4-1—Maglev Suspension Concepts



SOURCE: U.S. Department of Transportation, Federal Railroad Administration, *Assessment of the Potential for Magnetic Levitation Transportation Systems in the United States* (Washington, DC: June 1990).

allow a 30-percent greater speed through curves than conventional trains, but the benefit for maglev of tilting vehicles or banking guideways depends on the particular alignment in question. Many see interstate highway right-of-way as desirable for maglev guideways or high-speed rail tracks because of its limited access and potential low cost compared with other rights-of-way, but even interstates, which were designed for 70 mph, are often too curvy for current maglev designs to approach top speed. It has been

Box 4-A—Maglev Suspension Concepts

High-speed magnetically levitated (maglev) vehicles use one of two possible suspension technologies: electromagnetic suspension (EMS) or electrodynamic suspension (EDS). EMS maglev relies on magnetic attraction between the vehicle-mounted electromagnets and the underside of the guideway. The lower portion of the vehicle wraps under the guideway and is suspended by magnetic forces lifting it up toward the bottom of the guideway. EDS maglev relies on magnetic repulsion to keep the vehicle suspended from the guideway. For propulsion, all high-speed maglev designs use a linear synchronous motor, with power supplied to windings on the guideway ("active guideway"). With no physical contact between the vehicle and guideway at cruising speeds, and few moving parts, maglev produces no friction and has the potential for low maintenance compared to steel-wheel systems.

EMS maglev, used on the German Transrapid system, requires sophisticated control of the gap between the vehicle and guideway, which must be maintained at about 8 millimeters. EDS maglev, such as that used on the Japanese National Railways design, uses superconducting magnets for suspension, allowing a gap about 10 times greater than that for EMS maglev. Consequently, EDS maglev does not require guideway tolerances as precise, and may have lower construction costs than EMS systems (see later discussion of costs). Current EDS prototypes, however, have poorer ride quality than EMS systems and require further development of suspension systems.

The HSST EMS technology uses a linear induction motor (LIM) with power transmitted to the vehicle by means of a wayside third rail and a sliding pickup system. This passive guideway technology offers a lighter and less costly guideway, but is limited to a top speed in the 180 to 200 mile per hour range, due to LIM inefficiencies and constraints on wayside power pickup.[1]

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[1] Chris Boon, Canadian Institute of Guided Ground Transport, Queen's University at Kingston, Ontario, personal communication, June 21, 1991.

Box 4-B—Alternative Concepts

Among the many high-speed ground transportation concepts that have been proposed are several variations of magnetic levitation (maglev) vehicles. Others use fundamentally different technologies for guidance and propulsion.

The MIT Magneplane, a reduced-scale operational model of which was built in the 1970s, uses an electrodynamically suspended vehicle with a guideway consisting of an aluminum sheet trough. This design allows the vehicle to bank through curves, theoretically enabling high speeds and acceptable passenger comfort. The Magneplane concept takes advantage of the ability of maglev's synchronous motor propulsion to control accurately the position of every vehicle in the system.[1] Thus, vehicle intervals could be on the order of 1 minute or less. Using offline stations and single-vehicle operations, the Magneplane has been proposed for high-frequency, nonstop service between stations.

Maglev concepts incorporating **partially evacuated tubes** have been proposed as a means of reducing aerodynamic drag and increasing fuel efficiency and speed. Since aerodynamic drag accounts for more energy consumption as speed increases, its elimination could enable speeds several times higher than conventional maglev, high-speed rail, or even passenger jets, with negligible energy consumption.[2]

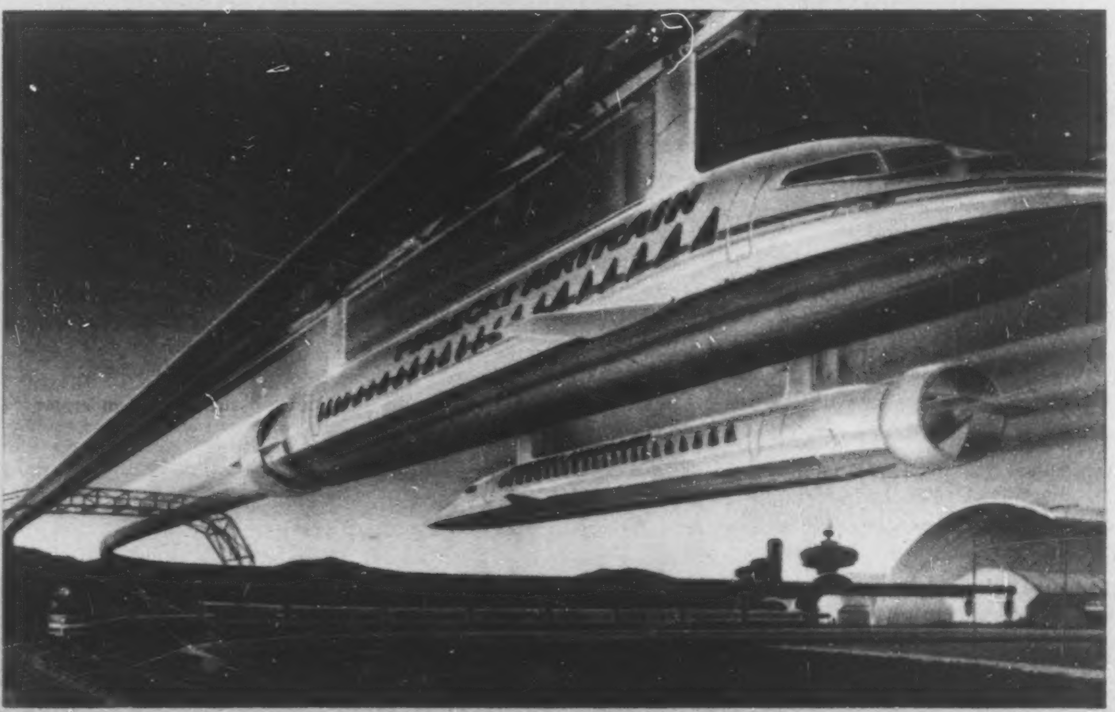

Photo credit: Popular Mechanics

The Piasecki AirTrain concept uses aerospace technology for high-speed guided ground transportation.

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[1] Henry Kolm, president, Magneplane International, Inc., personal communication, June 23, 1991.

[2] Gordon T. Danby, senior physicist, Brookhaven National Laboratory, personal communication, July 8, 1991.

Continued on next page

Box 4-B, continued

The Piasecki AirTrain design uses a powered turbofan for propulsion and braking. The AirTrain concept entails light-weight passenger cars suspended from hinged links to rails in an elevated guideway, with propulsion and braking from a ducted air propeller powered by a gas or diesel turbine engine or an electric motor that takes current from an overhead rail in the guideway. Centrifugal forces would cause the passenger car to bank when it enters a high-speed turn, thus naturally compensating for lateral forces and improving passenger comfort. The rails would be enclosed to prevent derailment and debris on the track. Since the AirTrain design calls for a ducted propeller for propulsion and retardation, it does not need a heavy weight (typical for all conventional wheel-on-rail systems) to produce the necessary friction between wheel and rail. The low vehicle weight could permit a lighter and less expensive guideway. Small retractable wings reduce vibration levels and minimize guideway and suspension maintenance costs.[3]

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[3] **Piasecki Aircraft Corp., *AirTrain High-Speed Ground Transport System*, report 99-X-21 (Essington, PA: Mar. 6, 1990).**

estimated that for the right-of-way of the New York Thruway between New York and Buffalo, added banking capability could increase the average speed at which maglev can travel and still provide acceptable passenger comfort from 170 to 220 mph.[3] Box 4-C provides basic information on high-speed rail concepts.

Most maglev concepts call for elevated guideways, which can add significantly to initial infrastructure costs. However, an elevated structure provides more flexibility in dealing with vertical curvature constraints, is less susceptible to interference from foreign objects or vandalism, and does not interfere as much with agricultural or other ground activities as at-grade construction. It also adds a margin of safety, since grade crossings are eliminated.

State of the Technology

Maglev technology has been developed primarily in Japan and Germany, where major, long-term, government-supported research programs are under way. High-speed rail technology is most mature in Japan, France, and Germany, where early research was government-supported and where systems are now in revenue service. Table 4-2 gives a brief technical comparison between maglev and high-speed rail, and box 4-D describes the state of foreign high-speed rail systems.

Maglev Systems in Operation

The only two maglev systems in revenue operation are relatively short, fully automated, slow-speed systems in Birmingham, England, and Berlin, Germany. The Birmingham Airport maglev, in operation for over 10 years, is a shuttle that runs along a 620-meter-long guideway linking the airport and railway station. Although the short distance does not require high speeds, maglev technology was chosen because it was thought to provide high reliability, low maintenance, and a high degree of automation. The system has not proven particularly reliable, and maintenance costs have been higher than expected because the system is unique and requires special parts. The Berlin system consists of a 1-mile line, most of which has two tracks, connecting the Berlin Philharmonic concert hall to a nearby metro station. Supported by the West German Minister of Research and Technology and the Berlin Senator for Transport and Public Utilities, track construction began in 1983 and was completed in 1986. Operation of this demonstration line began shortly thereafter. Neither system exceeds 50 mph.

U.S. Research

The High Speed Ground Transportation Act, passed in 1965, established the Office of High Speed Ground Transportation under the Department of Commerce, to explore advanced intercity ground transportation technologies. Although the stimulation of maglev research was not a major motivation behind this act, most early maglev work occurred around the time of its passage. The earliest U.S. work on maglev systems was carried out by Brookhaven National Laboratory, the Massachusetts Institute of Technology, Ford Motor Co., Stanford Research Institute, Rohr Industries, Boeing Aerospace Co., The Garrett Corp., Mitre Corp., and TRW Systems, Inc. Maglev work in the United States—other than feasibility studies and technical assessments conducted by government, industry, and universities—essentially ended in 1975, with the

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[3] Richard Gran, Grumman Corp., personal communication, Apr. 2, 1991.

Box 4-C—High-Speed Rail Transportation

Although high-speed rail is similar to conventional electrified passenger rail, higher speeds are achieved through dedicated rights-of-way, lighter vehicle weight, more powerful propulsion, and more precise track tolerances. The Japanese Shinkansen and French TGV steel-wheel systems operate at high speeds over exclusive track and have energy use and air quality benefits similar to those projected for magnetic levitation (maglev) systems. The TGV is also able to travel over high-quality conventional track, albeit at lower speeds, and thus its trains can penetrate city centers without extra right-of-way acquisition or construction. Existing TGV track has been built for anticipated cruising speeds of 250 miles per hour (mph), although speeds above the current 186 mph will require improvements in train technology. Still, some view regular speeds of greater than 200 mph as achievable by the end of the century.[1] Recent track tests of the TGV at 322 mph raise the possibility that such technology may become even more competitive with air travel or possible maglev systems.

High-speed rail shares certain characteristics with maglev (and interstate highways), including the need for total grade separation (at least along high-speed stretches of routes), expensive right-of-way construction (either new track or upgrading existing track), and tunneling or bridge work to avoid vertical and horizontal curves and maintain "fast" right-of-way and high ride quality. Maglev is able to negotiate steeper grades than high-speed rail. Both maglev and high-speed rail use automated speed and interval control, limiting the responsibility of onboard operators during routine operations and providing automatic override in the event of operator error or incapacity.

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[1] Barry James, "French Technology," *International Herald Tribune*, Oct. 31, 1990, pp. 15-16.

Table 4-2—Comparison of Maglev and High-Speed Rail

Maglev	High-speed rail
Possible top revenue speeds of 300 mph.	180 mph speeds on straightaways, 200+ mph revenue speeds achievable before end of decade.
Totally new infrastructure required; higher initial construction cost; possibly low maintenance costs.	New right-of-way and tracks needed for high speed, but existing tracks might be used (at low speeds) for urban operations; lower construction cost.
Noise level equal to or lower than high-speed rail at identical speeds. Quieter at low speeds because no friction (EMS).	Noise level of 85 to 90 decibels at a distance of 25 meters (82 feet) from the track at train speed of 160 mph. At 185 mph, noise levels can be in the 90- to 100-decibel range.
No high-speed revenue experience.	Fatality-free revenue experience.
Less energy use at low speeds.	Consumes similar amounts of energy per seat-mile as projected for maglev at similar high speeds.
Faster acceleration than high-speed rail.	
Can climb steeper grades than high-speed rail.	

KEY: mph = miles per hour; EMS = electromagnetic suspension.

SOURCE: Office of Technology Assessment, 1991.

Box 4-D—High-Speed Passenger Rail Abroad

High-speed rail systems have been in successful commercial operation for several years. Two of the best known systems are the TGV in France and the Shinkansen in Japan. Germany has a prototype high-speed train, the Intercity Express (ICE), which is designed for speeds between 150 and 180 miles per hour (mph). More than 40 German trainsets are now being manufactured, and revenue service began in 1991 on the Hamburg-Frankfurt-Munich line. (The U.S. Amtrak Metroliner, which achieves speeds of 125 mph along some stretches between Washington, DC, and New York City of the Northeast Corridor, is the only U.S. rail service that approaches the speeds of foreign high-speed systems.)

In France: Train a Grand Vitesse (TGV)

The TGV, France's high-speed rail system, began operations in the early 1980s. Construction on the newest line of the TGV, the Atlantique, began in 1985. The line is Y-shaped and consists of a main line between Paris and Courtalain and two auxiliary branches. The western Paris-Le Mans branch was completed in 1989, and the southwestern Paris-Tours line was completed in 1990. Total estimated cost is 16 billion francs ($3 billion) for construction of 163 miles of track and rolling stock. The line includes 13 miles of tunnels, located mainly in Paris and the Loire Valley, and 2 miles of viaducts in the Loir, Cisse, Loire, and Cher Valleys. Maximum design speed is 300 kilometers per hour (km/hr) (186 mph), with turnout crossing speeds between 160 and 220 km/hr (100 and 136 mph).

Land belonging to the SNCF, the French national railway company, the government, or alongside existing rail or highway right-of-way was used for 60 percent of the Paris-Courtalain stretch. To avoid level crossings, there are more than 310 structures along the line, including 164 road bridges and 139 rail bridges. Continuous welded rail with reinforced concrete crossties is used throughout. The line is electrified and uses five power substations. A control center located at Paris-Montparnasse includes telemetry and remote control equipment for crossovers between the two tracks, spaced out along the line at approximately 14-mile intervals. It also controls electric power feed and can intervene via radio links with all trains on the line. Fifteen satellite stations house safety equipment for each crossover site. The track-to-locomotive transmission system sends signaling information to the cab, where the driver reads it on the control panel. The trainsets include 2 power cars, one at each end, and 10 trailers. The power car wheelsets use electric brakes, and the trailer wheelsets use antiskid disc brakes.[1]

The TGV's power and adhesion, and the dedication of the high-speed corridor to passenger service with its light loads, made possible a line with gradients of up to 3.5 percent (on the Paris to Sud Est line—the maximum grade on the Atlantique line is 2.5 percent) instead of the usual 0.5- to 0.8-percent gradient. As a result, the line could be routed over plateaus where large-radius curves could be easily laid out, and thus avoid valleys, which are often sinuous, densely populated, and furrowed by waterways and roadways—all of which increase construction costs. The TGV lines are compatible with existing track and thus the trains can penetrate city centers and serve all major stations on the line.[2]

In Japan: Shinkansen (Bullet Train)

The Shinkansen long-distance, high-speed railways include two groups, the Tokaido and Sanyo Shinkansen, which run southwest from Tokyo, and the Tohoku and Joetsu Shinkansen, which serve the regions to the northeast. The Tokaido Shinkansen began service between Tokyo and Osaka (515 km) in October 1964, just before the Tokyo Olympic games. In March 1972 the Sanyo Shinkansen began operating between Osaka and Okayama (161 km). The Tohoku Shinkansen, which runs north from Tokyo, began operation between Omiya and Morioka (465 km) in June 1982. The Joetsu Shinkansen runs across Honshu between the Sea of Japan and the Pacific Ocean, and began operation between Omiya and Niigata (270 km) in November of the same year. When the Japanese National Railways was privatized in 1987, these lines became the property of the new

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[1] SNCF, Direction de la communication, "The TGV Atlantique: Construction of the New Line," informational document, June 1986.

[2] SNCF, Direction de la communication, "The Railways of France," brochure, n.d.

Continued on next page

Box 4-D, continued

Shinkansen Holding Corp. Over 2-1/2 billion passengers have been carried on the Shinkansen without injury. The maximum speed for the Tohoku and Joetsu Shinkansen is now 150 mph. Five additional routes are scheduled for future construction, including extensions from Morioka to Aomori, Takasaki to Osaka, Fukuoka to Kagoshima, Fukuoka to Nagasaki, and Aomori to Sapporo.[3]

The Shinkansen Holding Corp. owns the four Shinkansen lines—Tohoku, Joetsu, Tokaido, and Sanyo—and leases them to three of the passenger railway companies: the East Japan Railway Co., Central Japan Railway Co., and West Japan Railway Co. The fees are calculated according to the traffic volume of each Shinkansen line and other factors. The Shinkansen's ability to take passengers directly from city center to city center makes it competitive with airline and expressway transportation.[4]

As with many other railway systems, Shinkansen tracks are equipped with snow-melting facilities to prevent railway switch points from freezing in cold weather. Additional measures are taken for lines that pass through areas with heavy snowfall. Measures to prevent snow from adhering to or penetrating the operating mechanisms of the cars include covering the lower parts of the cars and using centrifugal snow separators, which remove snow from the intake air.[5]

Trains operating in areas prone to earthquakes are protected by a combination of earthquake detection and control systems, including seismometers installed every 20 to 80 km along the line. If land cables are damaged by large earthquakes, a communications satellite system will be used to transmit information.[6]

Other High-Speed Rail Systems

The principles of tilting train technology are independently rotating wheels mounted on guided axles, a low center of gravity, light weight, and swivel coupling of car bodies. Development of one tilting train, the Spanish Talgo, began in the 1940s. The latest model, the Talgo Pendular, is designed for a maximum speed on straight track of 125 mph. It is designed to round curves safely and with no passenger discomfort at speeds 25 percent faster than that of conventional trains.[7]

The Talgo trainset is made up of a succession of rigid cars articulated to permit the train to negotiate curves but prevent vertical or transversal displacements between cars. When rounding a curve, acceleration felt by the passenger depends on the tilt of the car and is significantly reduced if the car is tilted in toward the center of the curve. Thus, a tilting train can substantially increase its speed around curves compared with conventional trains. The Talgo system is based on raising the level of suspension above the center of gravity; the air springs of the main suspension behave elastically, allowing the car to tilt naturally around curves as a result of centrifugal force. The Talgo train also features an automatic gauge-changing mechanism to accommodate different track gauges.[8] Other tilting train configurations are manufactured by Bombardier of Canada, Asea Brown Boveri, a Swedish-Swiss consortium, and Fiat of Italy.

The Swedish X-2000 and the Italian Pendolino use conventional track and employ active tilt technology, using powered actuators, to reduce passenger discomfort when traveling through curves and to enable curve speeds 25 to 40 percent faster than those of conventional trains. Tilt technology is being considered for the Northeast Corridor to reduce travel time between New York and Boston to under 3 hours (presently

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[3] East Japan Railway Co., Shinkansen brochure, n.d.

[4] Ibid.

[5] Ibid.

[6] Ibid.

[7] RENFE, "Talgo: An Up-To-Date Train; A Long History," informational document, n.d.

[8] RENFE, "Talgo Pendular," informational brochure, n.d.

Continued on next page

Box 4-D, continued

4-1/2 hours) and between Washington and New York to under 2 hours, 15 minutes without having to acquire new rights-of-way.

Obstacles to Conventional High-Speed Passenger Rail

Most obstacles to conventional high-speed passenger rail systems center around the high cost of rights-of-way. Operating faster passenger trains would require in most cases a new roadbed and in some cases a separate right-of-way, because most of the track now used for passenger trains is also used by freight trains. Scheduling high-speed passenger trains on the same track with slower speed freight trains presents serious traffic and scheduling difficulties. In addition, freight trains, because of their heavier weight, cause comparatively more track wear than passenger trains, and passenger trains tolerate less track wear. Furthermore, freight trains cause tracks to come out of alignment more quickly, and because passenger trains require more precise alignment, track maintenance is more expensive for track used for both passenger and freight transport. (However, TGV trains in France operate at speeds up to 136 mph on track shared with conventional freight and passenger trains.)

Since grade crossings of railroads and highways are where the highest percentage of fatal rail-related accidents occur in the United States, it is generally agreed that high-speed trains should not operate over highway grade crossings. However, the cost of eliminating grade crossings from existing mixed traffic lines is considerable. In a study of the proposed Houston-Dallas-Fort Worth corridor,[9] for example, the cost of grade separations for highways, which included 135 structures, represents 17 percent of the total right-of-way-related costs. Most European authorities have accepted higher speed service (up to about 100 mph) without the elimination of all existing grade crossings.

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[9] Texas Turnpike Authority, "Texas Triangle High Speed Rail Study," unpublished report, February 1989.

termination of Federal funding for high-speed ground transportation research. In fact, U.S. research activity for all mass transportation, as reflected by R&D outlays by the Federal Railroad Administration (FRA) and the Urban Mass Transportation Administration (UMTA)[4] declined steadily through the 1980s (see table 4-3).

Table 4-3—Funding for Freight and High-Speed Ground Transportation Research

Years	Federal Railroad Administration R&D outlays (in millions of dollars)	Comments
1965-75	$15.0	On high-speed ground transportation
	2.3	On maglev
1980	63.0	Since 1980, these outlays have gone toward freight rail R&D.
1981	55.1	
1982	34.5	
1983	18.5	
1984	14.7	
1985	16.2	
1986	15.4	
1987	10.9	
1988	10.6	
1989	7.0	

SOURCE: Office of Technology Assessment, 1991, based on U.S. Department of Transportation data.

The National Maglev Initiative

As a result of legislative action in 1990,[5] directing the U.S. Army Corps of Engineers (the Corps) to prepare and implement a plan for a national maglev program, the Department of Transportation (DOT), the Department of Energy (DOE), and the Corps developed what is now known as the National Maglev Initiative (NMI). The NMI is a 2-year, $25-million program to assess the engineering, economic, environmental, and safety aspects of maglev. A major program report, planned for fall 1992, will include technical and economic assessments, options for developing U.S. capability to surpass existing foreign technologies, and recommendations on whether to pursue future development. Twenty-seven contracts, totaling $4 million, are currently being awarded to examine various subsystem technical issues, such as low-cost guideway construction, control systems, obstacle detection, and magnet design. One more set of contracts will be awarded shortly to examine various system concepts. Since the fiscal year 1993 budgets are now being prepared by the agencies and many of the results of the NMI are not expected until late 1992, it will be too late for the latter to influence the former.

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[4] Both the Federal Railroad Administration and the Urban Mass Transportation Administration are part of the U.S. Department of Transportation.

[5] Appropriations Conference report 101-235, for the Energy and Water Development Act of 1990.

Blending staff from three different cabinet-level departments has not been easy, and NMI team members have struggled to establish an effective working group. FRA has primary Federal responsibility for rail matters and has taken the lead role. FRA staff's technical expertise and experience in conventional rail safety and certification are transferable to some extent to high-speed rail and maglev. However, the tasks of developing guidelines and revised regulations for maglev and high-speed rail safety features and requirements have required reaching outside the agency for technical assistance.

Argonne National Laboratory (ANL) of DOE, which has substantial research experience in energy and propulsion systems, is playing the major role for the NMI in technical issues regarding levitation, guidance, and propulsion through its Center for Transportation Research. The Argonne Center is also studying vehicle-guideway interactions, developing requirements for test facilities, investigating superconductor applications, and conducting laboratory experiments on biomagnetic effects.[6] The Army Corps is providing expertise and assistance with guideway construction techniques and construction management.

FRA is depending heavily on staff from the Volpe National Transportation Systems Center (VNTSC) in Cambridge, Massachusetts, for support and administrative help for maglev research, in establishing safety testing requirements and, eventually, developing new standards. VNTSC is assisting FRA in conducting risk assessments, evaluating the safety of foreign systems, market and economic research, vehicle and guideway research, administering research contracts, and investigating the health effects of electromagnetic fields (EMF). Other portions of the EMF work are being performed by the Environmental Protection Agency (EPA) and ANL.

Other Research

DOT is also funding a study by the Transportation Research Board (TRB) to investigate possible use of maglev and high-speed rail technologies in U.S. corridors. In addition, a special committee on maglev transportation made up of technical experts has been created within TRB to review work of the NMI.

Status of German Maglev

German Government-supported maglev research began in 1969,[7] when the Federal Minister for Transport commissioned a study on high-speed, track-bound, ground transportation. In the early 1970s, the firms AEG, Siemens, and Brown-Boveri commissioned a 150-mph EDS maglev vehicle in Erlangen, which used superconducting vehicle magnets to attain a 4-inch levitation height and used linear synchronous motor propulsion.[8] In 1977 the West German Federal Minister of Research and Technology decided to concentrate development work on attractive suspension (EMS) designs. A test facility with a 19.5-mile track was put into operation in Emsland in northwest Germany in 1983, where more than 62,000 miles of tests have been conducted to date.[9] Over $1 billion has been spent on what is called the Transrapid maglev project, and the vehicle has been developed to the preproduction prototype stage and tested extensively. Transrapid International was formed initially as a consortium of several German companies and institutes.

With Krauss Maffei, MBB, and Thyssen Henschel as the principal participants, and support from the German Federal Ministry of Research and Technol-

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[6] Donald Rote, Argonne National Laboratory, personal communication, July 3, 1991.

[7] The earliest research on electromagnetic suspension maglev was conducted by the German scientist Hermann Kemper in the early 1920s.

[8] S. Kuznetsov, PSM Technologies, Inc., personal communication, July 2, 1991.

[9] William Dickhart, consultant to Transrapid International, personal communication, June 28, 1991.

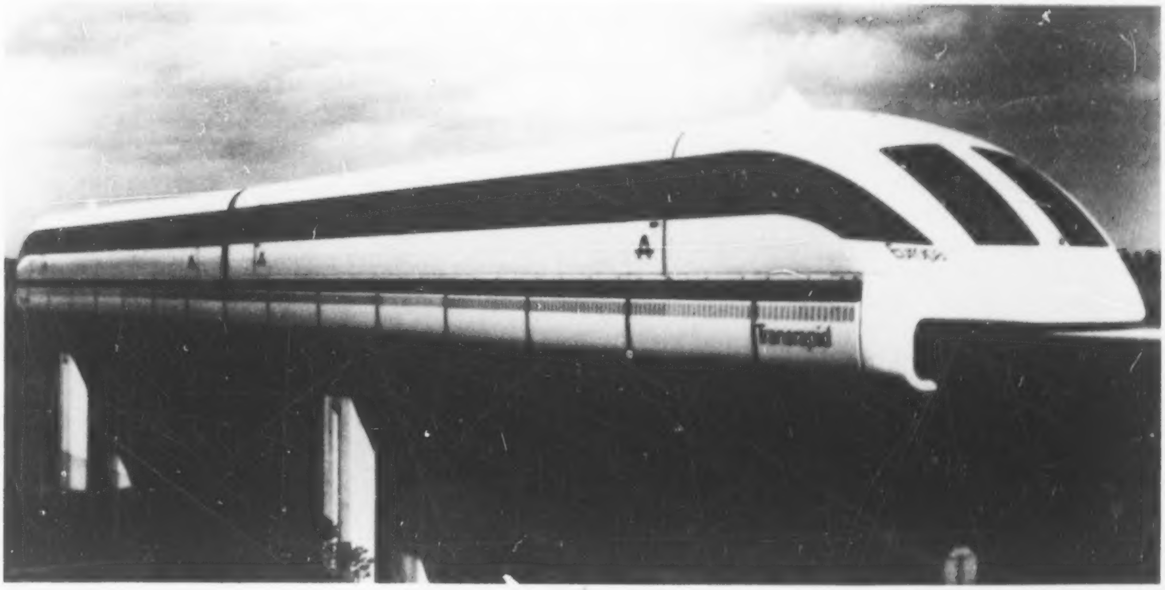

Photo credit: Magnetschnellbahn AG

The Transrapid maglev has been tested since the mid-1980s at a test track in Emsland, Germany.

ogy, the consortium has since been renamed Magnetschnellbahn and now includes Daimler-Benz, AEG, and Siemens. The Transrapid 07, the most recent vehicle prototype, has a top speed of between 250 and 310 mph and accommodates 80 to 100 seated passengers per section. Although Transrapid technology is presently the most advanced of maglev prototype systems, some experts believe its precise guideway tolerance requirements could lead to more costly construction and higher maintenance costs than would characterize other concepts.[10]

A short maglev route connecting Cologne/Bonn and Duesseldorf airports and the city of Essen has been approved by the government, but the Transrapid system has not undergone complete certification testing (travel through tunnels, two-way traffic), and the project lacks the necessary private sector funding. The German Government has stipulated that the estimated DM 3.6 billion in capital costs for the route must be shared by private industry, the airports and airlines, and the state of North Rhine-Westphalia, and it is not clear that this condition can be met.[11] Several intercity routes are currently being considered by the German Government, but there is no firm funding commitment yet.

Status of Japanese Maglev

The Japanese Railway Technical Research Institute (RTRI), supported by the recently privatized Japanese National Railways, has developed an EDS maglev system that is some 7 years behind the Transrapid system in development. It is similar in concept to the early research conducted in the United States by Powell and Danby of Brookhaven National Laboratory. Work began in 1967, and R&D costs through 1990 exceeded $1 billion. The vehicle (MLU-002) has a design speed of about 300 mph and has been tested at a 7-km test facility in Miyazaki. It requires less sensitive tolerances between the vehicle and the guideway than does the German system, and thus may be less costly to construct and maintain. However, its ride quality is not satisfactory, and improvements are to be made in the

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[10] Richard A. Uher, director, High Speed Ground Transportation Center, Carnegie Mellon University, testimony at hearings before the Senate Committee on Commerce, Science, and Transportation, Subcommittee on Surface Transportation, Oct. 17, 1989.

[11] *Spektrum der Wissenschaft*, February 1990, p. 32.

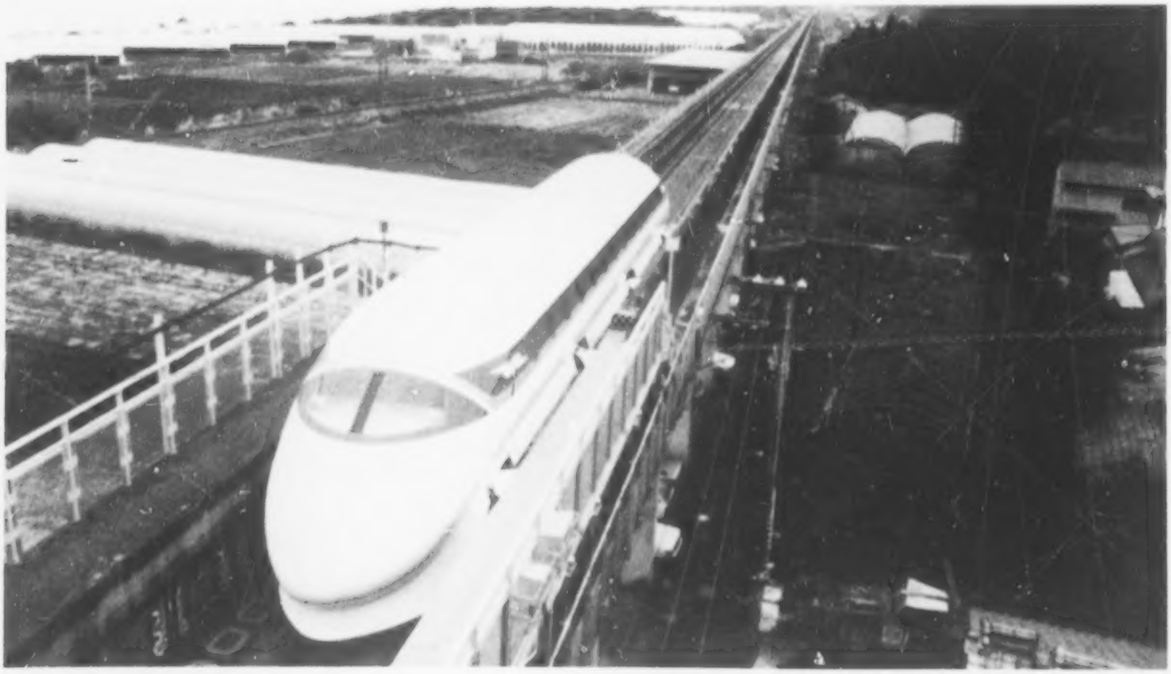

Photo credit: Railway Technical Research Institute

The Japanese MLU maglev vehicle uses electromagnetic (repulsive) suspension, which was invented in the United States.

suspension design. The JR system is the only maglev technology that uses high-temperature superconductors; this could bring modest gains in energy efficiency and reliability. Recent advances in developing high-temperature, superconducting materials are not likely to affect the overall feasibility of this technology.

A 27-mile test guideway is under development in Yamanashi prefecture for possible inclusion in a future revenue line between Tokyo and Osaka, and an extensive 4-year test of the system is expected to commence in 1993. The funding request for construction of the test track and for testing is approximately $3 billion, with the construction cost amounting to $2.3 billion.[12] RTRI receives funds from the Japan Railways Group, a consortium that includes six passenger railway companies, the Japan Freight Railway Co., and the Japanese Government (Ministry of Transportation). Construction of transportation facilities is handled by the Ministry of Construction.[13]

The other major Japanese system is the HSST EMS design with an unpowered guideway. The existing prototype, the HSST-100, has a top speed of 60 mph, but the HSST-200 and HSST-300 design concepts could reach 125 and 186 mph, respectively. Development of this system began in 1975 by Japan Airlines (JAL); the technology was transferred to the HSST Corp. in 1985. Since 1981, the HSST system has received no government funding, and financial support has come mainly from JAL. As of mid-1988, over $40 million had been spent on the R&D program. The HSST-100 maglev has been demonstrated extensively but has never realized its top design speed during these demonstrations because the tracks have been limited to lengths of less than 1 mile. It remains under development with no estimated completion date. Because

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[12] Canadian Institute of Guided Ground Transport, *Update of Super-Speed Ground Transportation Technology Development Status and Performance Capabilities*, report No. 89-16 (Kingston, Ontario, Canada: Queens University, May 25, 1990), p. 4.7.

[13] Uher, op. cit., footnote 10.

MITSUKOSHI
HSST

Photo credit: HSST Corp.

This low-speed maglev vehicle, the Japanese HSST, has carried visitors at expositions in Canada and Japan.

of its relatively low maximum speed in relation to other maglev designs, the HSST system will probably not compete with the RTRI system over longer routes. However, the technology is more mature, and because of its relative design simplicity and low guideway costs, it might find early applications in people mover and commuter service.[14]

Maglev R&D Needs

Some maglev R&D needs are unique to either EMS or EDS systems, while others are shared by both. Some areas needing further development, like switching and low-cost guideway construction, will not preclude construction of short, simple maglev routes, whereas other areas, such as magnet refrigeration and control of EMF for EDS, must be adequately addressed before revenue operation can proceed.

Switching is an important subsystem that needs further development for both EMS and EDS. The Emsland test track in Germany uses moveable guideway segments, but other (nonmechanical) concepts for EMS and EDS maglev have been proposed, such as electromagnetic switching, that could possibly provide higher switching speed and reliability without moving guideway structural members.

Since guideway design and construction represent the majority of total system cost, it is important to minimize this cost component. Research is needed to develop optimal guideway shapes that make the most efficient use of materials and yet meet requirements for tolerance and low maintenance (see later cost discussion for tradeoffs associated with various guideway concepts). Construction and fabrication methods that minimize onsite time and labor requirements and thereby reduce cost are also needed.

Less developed than EMS maglev, the EDS maglev still requires considerable research and testing. Further development needs for EDS maglev include: negotiating curves while maintaining adequate stability, cooling the superconducting magnets, designing suspension systems for high ride quality, and limiting EMF in the passenger compartment (see EMF discussion later in this chapter). These areas must be adequately addressed before any system will be commercially feasible. Progress has been made in the last two areas by the latest Miyazaki test vehicle using niobium-titanium magnets and active shielding of the passenger compartment.[15]

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[14] Rote, op. cit., footnote 6.

High-speed rail, although a mature technology compared with maglev, needs further development, if it is to achieve speeds of 200 mph or more. R&D needs include braking capabilities, wheel/rail dynamics, and electric current collection techniques.

Economic Considerations

Since infrastructure costs make up the majority of upfront system costs, and routes are not easily changed once they are constructed, it is critical that both a need and an adequate ridership for maglev or high-speed rail are established before routes are approved. Extensive market research is needed for understanding of modal preferences, travel time needs, and door-to-door travel trends for maglev; better cost and pricing information is available for high-speed rail, making potential ridership easier to estimate.

In a 1983 study OTA found that the following characteristics are important for a high-speed surface transportation corridor:

- cities grouped along a route giving major passenger travel flows in the 100- to 300-mile trip range;
- cities with high population and high population densities;
- a strong "travel affinity" between cities; and
- cities with developed local transportation access to feed the high-speed rail line.[16]

Travel between city pairs with major passenger travel flows in the 100- to 300-mile range generally occurs by air or automobile, so for a maglev or high-speed rail service to be successful, significant shifts would have to be made away from air or automobile travel. Although connections are important if a maglev or high-speed rail system is to compete with automobiles, they are less critical if the system is designed to serve the air travel market.

Some projected shifts to maglev are likely to be opposed by private-sector transportation providers, such as some airlines and rental car companies, which have already attempted to block implementation of such new systems. In the Texas corridor (see table 4-1 again), for example, Southwest Airlines, which operates extensively between cities along the route, has lobbied successfully for legislation that prohibits public financing of high-speed rail. However, some airlines might be supportive of new surface transportation systems that were not direct market competitors. In addition, construction of the Orlando Airport-International Drive maglev route has encountered resistance from the airport authority, who feared a loss of rental car business to a new transportation mode that will also be a tourist attraction.

Market Potential

Of the U.S. corridors with the characteristics listed above, only the New York-Washington, DC, rail corridor of Amtrak, where speeds of 125 mph are reached, currently provides airline-competitive rail service. Indeed, Amtrak carries more passengers between these cities than does any single airline. At present, service on other rail corridors is too slow or too infrequent (or both) to compete successfully with airlines. Other city pairs may be strong candidates for intercity maglev or high-speed rail service, but independent, detailed ridership forecasts and cost-benefit analyses are needed to help determine whether public support is warranted.

Estimates of potential ridership are usually based on origin-destination data (or estimates thereof) for air, rail, automobile, and bus traffic, and on projections of future demographic trends. Reliable data for automobile travel and for all door-to-door trips are next to

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[15] Kuznetsov, op. cit., footnote 8.

[16] U.S. Congress, Office of Technology Assessment, *U.S. Passenger Rail Technologies*, OTA-STI-222 (Washington, DC: U.S. Government Printing Office, December 1983), p. 29.

Photo credit: East Japan Railway Co.

The world's first high-speed rail service was provided by the Japanese Shinkansen (bullet train).

impossible to obtain, making intercity ridership for new maglev or high-speed rail systems extremely difficult to estimate. Uncertainties in forecasting and in projecting fare revenues are among the reasons that raising private capital for financing new systems has proven so difficult. (See chapter 2 for further details.)

Population and travel density determine the size of the potential market for maglev or high-speed rail service. The greater the population density, the more highly developed the transit system is likely to be, which can ease access to and egress from the high-speed line. For example, the ability of the Northeast Corridor to provide rail service is aided by the substantial local transit systems feeding the trains. Japanese experience with the Shinkansen, a high-speed railway, is similar; JR figures for 1982 indicate that the access to the Shinkansen from home to station is 75 percent by public transit, 20 percent by taxi, and 5 percent by automobile. Access from the train to final destination is 60 percent by public transit, 35 percent by taxi, and 5 percent by auto.[17] Comparable figures for New York and Washington, DC, confirm this pattern. Without convenient access to stations, some potential ridership for high-speed intercity rail or maglev is lost.

Other possible markets suggested for maglev are downtown-to-airport or suburban service. Speed requirements for such a system would not be as high as for intercity travel, so maglev system characteristics would be similar to those of conventional commuter rail lines. At speeds in the range of 50 to 60 mph, maglev could have some advantages over conventional rail in that it would probably be quieter and could require less maintenance.

Costs

Guideways and tracks, including power and communication equipment, account for the majority (80

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[17] Ibid., pp. 31-35.

Table 4-4—Comparative Economic Data for 250-mph Maglev and 200-mph High-Speed Rail

Categories	Maglev (EMS)[a] (200 seats)	High-speed rail (350 seats)
Vehicle cost	$7.2 million (2 sections)	$24 million
Guideway cost (per mile)	$10 million to $40 million: not firmly established and highly dependent on route and guideway parameters	$4 million to $20 million
Station costs (3 stations)	Comparable for both: $13,500/foot of platform; $3,000/parking space; $8.5 million/station for 500-foot platform and 600 parking spaces	
Vehicle operation and maintenance[b]	$0.028/seat-mile	$0.025/seat-mile
Fuel efficiency (seat-mile/gallon)	Estimated at 440 depends on suspension	540

KEY: EMS = electromagnetic suspension.

[a] Comparable data for electrodynamic suspension were not available.

[b] A load factor of 0.65 is assumed—i.e., about 65 percent of the seats are filled.

SOURCE: Office of Technology Assessment, 1991.

percent or greater) of initial system costs for maglev and high-speed rail. Since no high-speed, revenue maglev systems exist, these costs can only be roughly estimated. Cost is affected by the degree of urbanization and system size. The major items are design and engineering studies, right-of-way acquisition, track or guideway construction, tunneling, station and facilities construction, purchase of vehicles and signal and control equipment, prerevenue testing, and modifications to existing roads, bridges, rail lines, or other structures. Estimates of guideway costs from maglev corridor studies range from $10.6 million (includes some single track sections) to $60.9 million per mile. Comparable cost estimates made by experts for high-speed rail, based on existing systems, range from $8 million to $3[illegible] million per mile of electrified double track, including land acquisition.

Day-to-day operating costs, which include wages, fuel, and maintenance, are the second major set of relevant factors. Maglev operating costs are believed to be similar to current high-speed rail operating expenses because both systems consume similar amounts of energy, although personnel requirements may differ between the two systems. Maintenance for maglev depends on the system design and operating practices. Maintenance cost estimates range from appreciably lower than high-speed rail (because there are few moving parts) to appreciably higher (guideway tolerance and equipment needs may require frequent inspection and ongoing maintenance). See table 4-4 for a summary of cost data for maglev and high-speed rail.

Maglev guideway costs could vary greatly, depending on the system design. Because EDS maglev would use a lighter vehicle and require less precise guideway tolerances, its construction costs are estimated to be lower than those for EMS. However, costs depend greatly on beam properties—such as cross-sectional area, material, and stiffness—so it is difficult to make general comparisons between EDS and EMS construction costs. For example, computer-integrated manufacturing can lower fabrication costs for all kinds of beams and make high EMS tolerance requirements less of a cost factor. On the other hand, some EDS concepts suggest box and circular beams, which could use less material than EMS beams and therefore be less costly. Since guideway costs make up a major portion of total system costs, all guideway options should be investigated. Generally, guideway costs for EDS do appear to be the same as or lower than for EMS guideways, all other factors being equal (guideway electronics, material costs, optimal shapes for beam).[18]

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[18] George Anagnostopoulos, Volpe National Transportation Systems Center, personal communication, Apr. 29, 1991.

Regulations and Safety

Because neither maglev nor high-speed rail systems exist in this country, many issues related to these technologies are difficult to address within the existing regulatory and safety framework. Such issues include the institutional framework itself, safety certification, vehicle standards, guideway and system performance standards, emergency response procedures, and environmental impacts.

Institutional Framework

Two Federal agencies have jurisdiction over high-speed ground transportation: FRA and the Federal Highway Administration (FHWA). FHWA's jurisdiction involves multiple right-of-way usage, including air rights, and grade crossings.[19] FRA has authority over all intercity passenger rail transportation and is charged with assuring the safety of maglev systems in the United States under the Rail Safety Improvement Act of 1988. All high-speed guided ground transportation systems (maglev, air-cushioned vehicles) have historically come under FRA authority, even though no such systems are currently operating in this country. Recognizing the inadequacy of the present framework to address maglev or high-speed rail safety issues, FRA embarked on a multiyear research program in 1989 to establish the appropriate safety measures that should be applied to these technologies.

FRA regulations relating to safety tend to be technology and component specific and were adopted from years of railroad operating experience. Although maglev systems consist of the same basic system elements as any guided ground or rail transport system, they use fundamentally different suspension and propulsion technologies. Therefore, most existing railroad regulations are not directly applicable, although the intent of some regulations is appropriate for maglev as well as railroads. Besides FRA standards, other Federal regulations could apply to maglev—Federal Aviation Administration (FAA) windshield strength standards and UMTA emergency preparedness procedures for rail transit, for example. FRA will have to modify its regulations and develop new ones to address maglev-specific safety issues. A number of foreign and other transportation industry safety standards and guidelines exist that could be applied to the proposed U.S. maglev systems (see box 4-E).[20]

Safety Certification

The only system for which even preliminary safety and certification guidelines have been proposed is Transrapid, which is the only high-speed maglev system advanced enough to be considered for revenue operation. Responsibility for safety assurance and proposing safety standards during technology development for Transrapid has rested on TUeV Rheinland (an independent certification authority), acting as an agent for the government of the Federal Republic of Germany. FRA will require Transrapid International to certify that the design, construction, and testing of the maglev system complies with TUeV's safety standards and with any construction plans and specifications submitted to FRA. Although no definite timetable has been set for issuing new regulations or guidelines, FRA does intend to establish testing requirements, including a list of safety-related tests to be performed by the operator of any maglev system prior to commercial operation of the system, and at regular intervals thereafter. The Orlando line could operate under a special demonstration waiver, if FRA requirements have not been issued by the time testing of that system begins.

At present, TUeV requirements state that the vehicle levitation and guidance functions will not be lost under any sequence of system failures, and that the vehicle will maintain its own suspension until it is brought to a stop by either central control or its own internal control system. This "safe hovering" concept requires that the vehicle come to a stop only at guideway locations where auxiliary power and evacuation means are provided. The vehicle must be able to reach the next allowable stop location independent of the wayside power system (i.e., relying solely on momen-

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[19] 23 CFR 646.

[20] For further information, see U.S. Department of Transportation, Federal Railroad Administration, *Safety of High Speed Magnetic Levitation Transportation Systems: Preliminary Safety Review of the Transrapid Maglev System*, DOT/FRA/ORD-90/09 (Washington, DC: November 1990); and Robert M. Doer et al., *Safety Relevant Observations on the X2000 Train as Developed for the Swedish National Railways* (Cambridge, MA: U.S. Department of Transportation, Volpe National Transportation Systems Center, December 1990).

Box 4-E—High-Speed Rail Safety Standards

High-speed steel-wheel-on-rail systems include all the technologies of conventional rail systems, but because vehicle and track standards for high-speed rail are more stringent, more and newer safety equipment must be in place. For instance, overhead bridges are commonly equipped with intrusion detection devices to provide warning if a vehicle breaks through a bridge railing and could fall onto the track area. At European grade crossings, where some high-speed trains routinely cross highways at 125 miles per hour (mph), on-train closed-circuit television, gates, and warning sounds are used. All routes on which trains exceed 125 mph have been grade separated. Other safety and route protection measures for high-speed rail include fencing to protect against intrusion on the right-of-way, induction loops, interlocking signaling, and speed monitoring. Automatic train detection, which uses the rail as an electrical conductor and senses trains when they close the circuit, activates warning and control systems to warn motorists—a technique that is standard grade-crossing protection for freight systems in North America.

European high-speed rail uses concrete crossties and elastic fasteners, which provide a more stable structure than the wood ties and cut spikes traditionally used in North America and are projected to have a life of 40 to 50 years under light-weight, high-speed trains. Amtrak's high-speed tracks between Washington, DC, and New York City use primarily concrete crossties.

Current U.S. rail operating practices, vehicle and track standards, and communication and signal system practices differ in many respects from pertinent foreign high-speed rail practices recommended by the International Railway Union (Union Internationale des Chemins de Fer), and from those of foreign railway companies presently operating trains at speeds of 130 mph or more. Design practices for tracks, roadways, bridges, and other structures in the United States are standardized in the recommended practices of the American Railway Engineering Association (AREA) and incorporated in 49 CFR 200-268. The passenger equipment interchange rules of the Association of American Railroads (AAR) were canceled effective Jan. 1, 1984, and republished as recommended industry practices. U.S. industry design standards are embodied in the recommended practices of AAR, AREA, and Amtrak specifications, but not all are enforced under the U.S. code.

Federal Railway Administration (FRA) vehicle crashworthiness regulations are based on the assumption of mixed freight-passenger traffic. They stipulate that vehicles be able to withstand certain compressive loads without permanent deformation and led to heavier trains than those on European or Japanese high-speed systems. Foreign high-speed rail systems are generally dedicated to passenger service and assume a greater need for collision avoidance and energy absorption during collisions. For high-speed power cars in Europe, the relatively low buff strength is compensated for by the varying use of energy-absorbing, or collapsible, structures at the cab ends to provide protection to the crew in the event of collisions. This protection is less than that provided by locomotives and self-propelled cars in North American service. This aspect is partially offset on high-speed lines, however, by severely limiting access to the tracks to reduce significantly the probability of collisions.[1]

Track standards also differ between U.S. and foreign systems. FRA categories track quality in six classes. Maximum permissible train speed is restricted to a specified limit for each class—the poorest quality track is class 1 and the best is class 6. Class 6 maximum permissible passenger train speed is 110 mph, and to exceed this, a railroad must petition FRA for a waiver of the rules. Europeans have established track standards in some areas for safe speeds of up to about 200 mph.

To provide for maintenance activities and unforeseen contingencies, virtually all lines handling high-speed trains are equipped with complete high-speed crossover tracks and bi-directional signals. Tunnels and other problem areas are provided with repeaters or auxiliary antennas to ensure reception and continuous voice communication.[2]

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[1] John Bachman, Bachman Associates, "Federal Law and Regulations Relevant to High Speed Rail Systems," working paper prepared for The Florida High Speed Rail Transportation Commission, September 1986.

[2] Transportation Research Board, "Safety Factors Related to High-Speed Rail Passenger Systems," *Transportation Research Circular 351* (Washington, DC: National Research Council, July 1989).

Continued on next page

Box 4-E, continued

The primary function of a signal system is to provide a warning early enough to permit a train to stop safely, and signal spacing is based on calculated stopping distances. Because stopping distance increases proportionally to the square of the speed, high-speed trains would require very long stopping distances, if conventional braking systems were used. (In an emergency, trains can change speed only, not direction.) After stopping distances have been determined for a particular type of vehicle's braking system on a specific line profile, European regulations add a 10-percent factor of safety to allow for poor adhesion, improperly adjusted brakes, low air pressure, and other variables. Typical American industry practice has been to add 15 to 25 percent as a safety factor. The automatic train control systems in Europe normally allow for 4 to 8 seconds (similar to U.S. practice) for the train operator to react and apply the brakes before the system applies an automated brake. The distance traveled during this reaction time must also be added to the stopping distance to determine the proper signal spacing (an additional 1,760 feet at 150 mph). In summary, the stopping distances for European high-speed trains that are used to determine signal spacing are appreciably shorter than those of typical American practice because of the additional braking capacity of the high-speed trains (dynamic and track brakes).[3]

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[3] Ibid.

tum or an onboard energy supply). The vehicle must also be able to bring itself to a safe stop without any input or guidance from the central control system.[21]

Maglev Vehicle Safety Standards

Maglev vehicles have both a primary and a secondary braking system, which function independently of each other and provide controlled braking. The primary brake is initiated by the central control system, which controls the propulsion motor (drive) to reverse vehicle thrust. Secondary braking is accomplished using longitudinal vehicle magnets to induce eddy currents in the track guide rails. Since the eddy current brake force decreases sharply with speed, the final emergency braking requires the vehicle to come to a stop on landing skids (in the case of Transrapid).[22]

There is concern that passengers cannot exit the vehicle safely in an emergency unless it is at a preestablished exit location. Evacuation chutes, like those on aircraft, and a walkway on the guideway leading to evacuation ladders are options that could alleviate this concern.

The structural design of the maglev vehicle is similar to that of aircraft, and the vehicle is not designed to withstand the buff forces railcars are required to withstand. Buff strength is defined as the amount of longitudinal compressive load a car body can take without permanent deformation. **In-depth evaluation of crashworthiness is essential.** FAA window glazing requirements might be considered for use in modifying existing FRA regulations.[23] Maglev vehicles might have pressure-sensitive doors similar to those required by European high-speed rail standards. U.S. standards also do not address the impact of lightning on maglev safety and operation.[24]

Guideways

A maglev guideway consists of bearings, beams, footings or foundations, and piers or columns spaced approximately every 80 feet. The guideway must have sufficient stability and stiffness to transmit all static and dynamic loads to the subgrade while meeting alignment requirements[25] and a service life commensurate with other system components. The guideway must withstand many forces and conditions over time: repeated vehicle loadings, high winds, erosion, oxidation, extreme thermal conditions, and other environmental factors.

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[21] Federal Railroad Administration, op. cit., footnote 20, p. 3-5.

[22] Ibid., p. 3-8.

[23] 49 CFR 223.

[24] Federal Railroad Administration, op. cit., footnote 20, p. 7-1.

Standards

Tolerances for guideways vary according to the maglev concept, but are typically more precise than normal construction tolerances for transportation structures in this country. One of the NMI staff's challenges is to consider developing structural standards for guideways and guidelines for how inspection and maintenance will be performed.[26]

Eliminating the possibility of or detecting the presence of people or objects on the guideway is crucial if casualties or collisions are to be avoided. Requirements for an intrusion detection system or a physical barrier are likely to be necessary to ensure the security of the guideway, especially in areas where the guideway is easily accessible.

Right-of-Way

If interstate highway rights-of-way are to be used for maglev, a number of issues must be addressed, including legality, construction and maintenance on limited access highways, safety impacts, and environmental impacts. Federal-aid highways and their associated rights-of-way are owned, operated, and maintained by the States, but both State and Federal Governments must approve their use. FHWA decisions on the use of Federal-aid rights-of-way are made on a case-by-case basis; there are no set guidelines. Current Federal law has a fair market value provision stipulating that a State must receive reimbursement for use of the right-of-way unless the right-of-way is owned by a publicly owned transit authority. (This may change; the 1991 surface transportation bill proposed by DOT eliminates the stipulation.) States may, however, charge for use of their right-of-way, as is commonly done with utilities.

State and local governments can acquire additional rights-of-way through the power of eminent domain in judicial condemnation proceedings. States vary in the extent to which they permit multiple uses of highway rights-of-way. Condemnation procedures often strictly limit the purposes for exercising eminent domain, including restricting use of the condemned land to specific purposes. Issues of whether and how State or local government rights-of-way can be used must be resolved, especially if maglev is built and operated by the private sector.

Since allowing the use of a Federal-aid right-of-way for maglev is a major Federal action requiring FHWA involvement, the compliance of a maglev system with provisions of the National Environmental Policy Act must be satisfied. The level of environmental analysis and documentation required to ensure compliance depends on the extent of the encroachment and the nature and extent of project impacts. The approval action may be either a categorical exclusion, an environmental assessment finding of no significant impact, or a request for an environmental impact statement.[27]

Safety Impacts

Present highway policy maintains the desirability of a clear zone, or unobstructed recovery area, in the median strip and along the edges of highways to allow room for vehicles leaving the road either to recover and return to the pavement or to run a reasonable distance before colliding with an object (see box 4-F). If maglev systems use elevated guideways in highway medians, questions must be resolved about the safety of the piers for vehicles and drivers, the impact of road vehicles on the piers, and the safety of the maglev vehicles. The potential for the crash of an 80,000-pound or heavier truck traveling at 55 mph or more into a concrete pier must be taken into account in guideway design if the piers are located near the roadway.

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[25] For Transrapid these are 0.1 inch per 32.8 feet, since its suspension system requires close tolerances.

[26] Federal Railroad Administration, op. cit., footnote 20, p. 7-1.

[27] Letter from the Federal Highway Administration (FHWA) Executive Director to FHWA San Francisco Regional Administrator, Apr. 4, 1990.

Box 4-F—Multiple Uses of Highway Rights-of-Way

The American Association of State Highway and Transportation Officials (AASHTO) has long been active in matters of highway policy and engineering. AASHTO's policy on highway rights-of-way states:

> A recovery area clear of unyielding objects should be provided. When provision of such an area is not practicable, any unyielding objects within its limits are to be made breakaway or are to be shielded by installation of crashworthy barriers or attenuators. Similarly, to the extent practicable, the pier and abutment supports for another highway or for a railroad overpass structure should be designed to provide a lateral clearance equal to the clear recovery area. The width of the recovery area is to be commensurate with the selected design speed and roadside conditions. The width is to be determined through application of currently accepted procedures. In restrictive areas, it may be necessary to construct barriers, walls, piers, abutments or other unyielding objects nearer to the traveled way than the width required for a clear recovery area. The minimum lateral clearance from the edge of the through lanes to the face of such objects shall be the shoulder width with appropriate crashworthy barriers and attenuators.[1]

Although AASHTO authority is not binding, most States and the Federal Highway Administration use these guidelines, and clear zones and recovery areas must be taken into account in decisions about maglev or high-speed rail route alignments. The Department of Transportation has recently begun a 6-month study, entitled "Shared Right of Way and Safety Issues for High Speed Guided Ground Transportation," which is examining the operation of maglev and high-speed rail along highway rights-of-way.

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[1] Francis B. Francois, executive director, American Association of State Highway and Transportation Officials, testimony at hearings relating to the development of high-speed transportation corridors, before the House Committee on Public Works and Transportation, Subcommittee on Surface Transportation, May 3, 1991.

Another area of possible conflict is the effect of the maglev or high-speed rail power systems, if any, on vehicle and highway electronics. Electronic fuel injection equipment and computers in automobiles and trucks are increasingly common. Also, sensor and communication technologies related to intelligent vehicle/highway systems must be taken into account in maglev system analyses.[28] Federal Communications Commission requirements related to electromagnetic emissions must be considered.

Emergency Procedures

Provisions must be made to allow passengers and employees to leave the vehicle and allow emergency response personnel to enter the vehicle at any location where an emergency can occur. In existing European high-speed rail systems and Amtrak, train crews are instructed and given practical training in routine and emergency public address system announcements as well as hands-on practice to protect, evacuate, and rescue passengers. This type of training is also provided by the railroad and car builders to fire departments and other emergency organizations located along the routes. Some railroads furnish detailed local maps to regional fire and rescue groups to expedite their access to train accident sites.[29] **At present, FRA has no guidelines, regulations, or standards addressing this issue. An emergency equipment and facilities response plan that addresses emergency response training and preparedness is needed.**

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[28] Francis B. Francois, executive director, American Association of State Highway and Transportation Officials, testimony at hearings relating to the development of high-speed transportation corridors, before the House Committee on Public Works and Transportation, Subcommittee on Surface Transportation, May 3, 1990.

[29] Transportation Research Board, "Safety Factors Related to High-Speed Rail Passenger Systems," *Transportation Research Circular 351* (Washington, DC: National Research Council, July 1989).

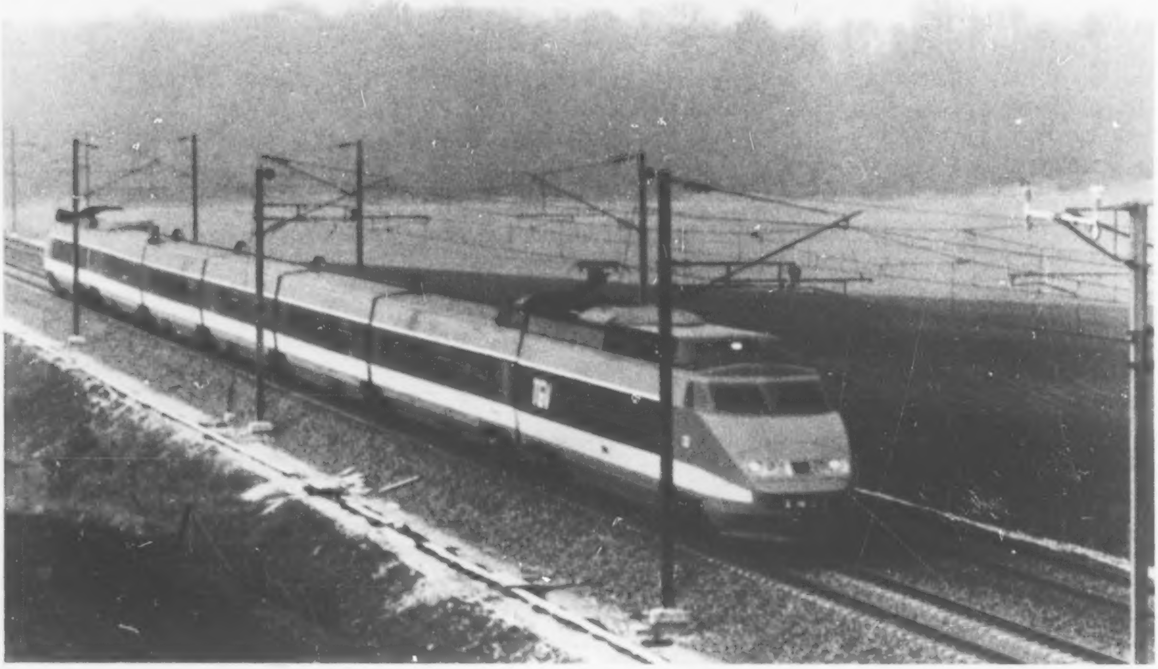

Photo credit: SCNF

The Train a Grand Vitesse (TGV) currently operates at high speeds along 1,100 miles of track in France.

Health and Environmental Issues

Maglev and high-speed rail systems face a number of potential health and environmental hurdles affecting their public acceptability, including electromagnetic fields and noise. Resolution of these issues is just as important as technical performance.

Electromagnetic Fields

One of maglev's consistent selling points has been its power source. Electrical power, the reasoning goes, provides a clean, efficient, and safe energy source. But as attention has focused recently on the possible harmful effects of EMFs, this selling point for maglev could turn out to be a major roadblock, depending on which suspension technology is used. The fields encountered in passenger cabins and along the wayside of an EMS system are on the same order of magnitude as ambient Earth levels and about the same as or below the field levels associated with common household appliances, such as microwave ovens, refrigerators, and hair dryers. With current EDS designs, however, DC magnetic field levels can significantly exceed acceptable limits, and measures will have to be taken to reduce these levels or to shield passengers and bystanders from their effects. In addition, existing Department of Health and Human Services rules regarding electromagnetic emissions must be considered in any maglev system. Appendix A describes what is currently known about EMF levels and their impacts on human health.

Air Quality and Noise

Neither maglev nor high-speed rail systems depend on petroleum for power and consequently do not degrade air quality where the vehicles operate. Moreover, they are projected to be four or more times as energy efficient as wide-body airliners.[30] Air pollution in the form of carbon dioxide emissions generally depends on power requirements. For electrified systems such as maglev, these emissions would have point sources rather than mobile sources and would probably not occur in areas where air quality is a concern.

Maglev and high-speed rail produce noise levels that increase with speed. Aerodynamic factors are the principal noise contributors for maglev. High-speed rail noise is affected by those factors plus wheel/rail interaction, the propulsion system, and a high-speed pantograph-catenary interaction.[31] Above about 150 mph, aerodynamic noise exceeds other sources of noise for high-speed rail. At speeds in this range and above, the vehicle can be heard many hundreds of feet from the right-of-way, and in populated areas, a reduction in speed for noise reasons alone (accompanied by sound barriers or other measures) may be necessary. At speeds above 170 mph, the TGV produces noise levels in the 90- to 100-decibel (dB) range.[32] By comparison, noise from a heavy truck traveling on the highway measures about 90 dB, while that from a jet takeoff measures 105 dB 2,000 feet away from the source. Table 4-5 summarizes the noise impacts of various transportation modes. Federal agencies, including DOT, EPA, and the Department of Housing and Urban Development, are involved in regulating noise impact. In addition, many municipalities have noise ordinances that must be complied with during construction and operation.

Institutional and Financing Issues

No matter how developed the technology, many institutional issues surround the approval, construction, and operation of new high-speed ground transportation systems, including who will operate them, on whose land they will be built, and who will finance them. The choice of potential operators, which depends on who owns the system and right-of-way, includes airlines, public transportation authorities, railroads, or other private providers. Careful consideration must be given to where these new systems are built, who will operate them, and whether more than one operator can use the same guideway or right-of-way.

Table 4-5—Noise Characteristics of Transportation and Other Activities

Activity	Sound level in decibels
Whispering	30
Light auto traffic at 100 ft	50
Conversational speech	60
Vacuum cleaner at 10 ft	69
Freight train at 50 ft	75
Shinkansen at 150 mph at 82 ft	80
Alarm clock at 2 ft	80
Riding inside a city bus	83
Transrapid at 185 mph at 82 ft	84
Heavy truck at 50 ft	90
TGV at 185 mph at 82 ft	91
Jet takeoff at 2,000 ft	105
Jet takeoff at 200 ft	120
Threshold of physical pain	130

SOURCE: Office of Technology Assessment, 1991, based on U.S. General Accounting Office data.

Community Acceptance

Objections on grounds of noise, EMFs, traffic congestion near new station sites (particularly in urban areas), and aesthetics are likely to be the major obstacles to gaining community acceptance. Intense public education, combined with adequate environmental protections, will be required before any system gains widespread popular support. Even with privately owned rights-of-way, which may not require as much official review, States would probably not proceed without full environmental compliance. Efforts to shorten the environmental impact assessment process could create public distrust, as was the case in the Los Angeles-San Diego project sponsored by the American High Speed Rail Corp.

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[30] U.S. Department of Transportation, Volpe National Transportation Systems Center, "Innovative Technology for Intercity Passenger Systems," unpublished draft report, Aug. 24, 1990, p. 37.

[31] A catenary is an overhead wire from which electrical current is drawn. A pantograph draws current from the catenary.

[32] The Canadian Institute of Guided Ground Transport, Queen's University at Kingston, Ontario, "Characterization of High-Speed Ground Transportation Technology Alternatives for U.S. Applications and Discussion of Key Issues and Questions," unpublished report, Nov. 28, 1990, p. 5-15.

Proposals calling for the construction of entirely new rights-of-way will require public agreement on land-use questions. Permission to use or buy a right-of-way in the United States would have to be sought from any number of organizations that could include States, municipalities, transit properties, airports, Amtrak, freight and commuter railroads, toll and turnpike authorities, utilities, and private citizens and organizations. The support for maglev or high-speed rail by local governments, institutions, environmentalists, and citizen groups will be influenced by projections of demand for the service, by the amount of urban land and areas of natural beauty through which the line must travel, and by the perceived need to reduce congestion elsewhere. Ironically the areas where maglev or high-speed rail are most likely to be successful are so densely populated that establishing new high-speed lines is difficult and costly. In constructing the TGV, high capital costs and environmental opposition were avoided by using existing, state-owned rights-of-way into and out of Paris. The line between Paris and Lyon encountered relatively little opposition because of the low population density between the cities.

If government subsidies are used to finance a new system, political disputes may occur over which areas should host it and what the appropriate site selection criteria would be. Local government support may well depend on whether a local stop is included in the new route. If a number of intermediate stops are made to satisfy local interests, travel time between large urban centers would increase, and the new system would be less competitive with other modes.

Intergovernmental and Financing Issues

Governments have played a strong role in transportation infrastructure development because relying on private funding is often not feasible (see chapter 2). Government support has been essential to the development of new transportation technologies—Germany has invested around $1 billion in the Transrapid; Japan is planning to spend $3 billion over the next decade on maglev development and testing; the TGV and Shinkansen systems were supported significantly by their respective national governments or railroads; the United States spent approximately $15 million on the High Speed Ground Transportation program from 1965 to 1975, roughly $2.3 million of which went toward maglev research.

Even if foreign-developed vehicle technologies are used, financing for construction of new infrastructure remains a huge obstacle. Financing for high-speed rail projects in this country was encouraged by a Federal law enacted in 1988 exempting from Federal income tax those revenues received on bonds issued for high-speed, intercity rail facilities. Choice of operator will affect labor regulations and costs and the amount of competition encountered from other modes. It is unclear, for example, how existing railroad labor statutes will apply to high-speed rail or maglev. Finally, acquiring the right-of-way, particularly in congested corridors, could prove to be a major obstacle.

Of the many high-speed ground transportation corridors that have been proposed, a few (Los Angeles-San Diego, Miami-Tampa-Orlando) have reached the stage where project financing has been seriously considered. Although most States have established policies that any high-speed rail or maglev project must be privately funded, no private entity has ever expressed willingness to bear the full costs of any proposed system. All projects have proceeded from assumptions (sometimes unstated) that the public sector will facilitate or financially support such activities as land acquisition for right-of-way, guideway or track construction, station construction, environmental mitigation, grade separation, and so forth.

Funding for major transportation projects typically comes from taxes or passenger fares, regardless of whether the project is publicly or privately financed. Mechanisms suggested for aiding high-speed rail/maglev projects include sales taxes, motor vehicle fuel tax revenues, bond issues, station development cost-sharing, developer fees, "capturing" increases in value of the land surrounding stations, tax-free status for project bonds, exemption or special status regarding environmental approval and fees, Federal loan and investment guarantees, special taxes, and diversion of funds from other public sources. Timely payment of interest during construction also appears to be very important in determining project profitability.

Other financing options include establishment of special taxing districts to allow projects to be financed by property taxes on local businesses, benefit assessments, tax increment financing, development impact fees, equipment leasing, and joint public-private development. DOT has proposed legislation permitting States to provide available highway rights-of-way at little or no cost to high-speed rail projects, including maglev. The current provisions for market-rate compensation of highway rights-of-way drive up the costs of high-speed rail and maglev projects, although there are good policy reasons, in many cases, for encouraging the co-location of transportation facilities. Another proposal under consideration would permit States to use Federal-aid highway funds to make highway facility adjustments to accommodate other modes, including high-speed rail and maglev. Such improvements might include alignment modifications, fencing, drainage, structural work, grade crossing elimination, and construction of modal separation barriers.[33]

Conclusions

Maglev and high-speed rail systems show considerable technical promise as high-volume, intercity passenger modes in selected corridors up to about 500 miles. However, any system would require substantial infrastructure investment initially, although high-speed rail and probably maglev systems have low operating costs relative to other modes. Maglev requires further development and local demonstration before it could enter intercity service in this country. Intercity high-speed rail systems are already highly developed and operating in Europe and Japan.

Economics and Market Potential

U.S. demographics and geography and the construction costs of implementing maglev or high-speed rail raise difficult financial and policy issues which must be addressed before any intercity system can go forward. Only a few U.S. corridors have population and travel densities comparable to the European and Japanese corridors currently enjoying high ridership. Thorough, independent market research, including analyses of current door-to-door travel trends, intermodal connections, modal preferences, and modal competition, must be undertaken to assess the potential ridership and benefits of new maglev or high-speed rail connections and determine which corridors are most likely to benefit from high-speed ground service.

Guideways and Right-of-Way

Right-of-way alignment must include long, straight sections or large-radius curves if maglev vehicles or high-speed trains are to achieve average travel speeds approaching maximum vehicle speeds. Existing interstate rights-of-way, which were designed for 70 mph, are not adequate for current maglev or high-speed rail concepts to achieve sustained high (150 mph+) speeds in many areas. **Acquiring rights-of-way in all corridors where maglev or high-speed rail could be used effectively would be both difficult and costly.**

Guideway design and construction represent the majority of total system cost. Further work is needed in developing optimal guideway shapes that make most efficient use of material and yet meet requirements for tolerance and low maintenance. Concepts that employ banking of the track or guideway as well as tilt of the vehicle could enable higher speeds through curves while still maintaining high passenger comfort levels. Construction and fabrication methods that minimize onsite time and labor requirements and thereby reduce cost are also needed.

Research and Development

The National Maglev Initiative marks renewed U.S. interest in maglev and will provide useful input regarding how or whether to pursue this technology. While results from the NMI are not yet in, it is clear that several technical issues need further work before maglev systems can begin revenue service.

EMF health effects are still unknown, but exposure levels from EMS maglev and high-speed rail are believed to be on the same order as those emanating from common appliances. EDS maglev produces higher DC magnetic fields, however, and will require design strategies and magnetic shielding for minimizing passenger exposure.

Further development needs for EDS maglev include: negotiating curves while maintaining adequate stability, cooling the superconducting magnets, limiting EMF in the passenger compartment, and cost re-

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[33] Elaine L. Chao, deputy secretary of transportation, U.S. Department of Transportation, remarks at Washington High Speed Rail Forum, Washington, DC, Nov. 9, 1990.

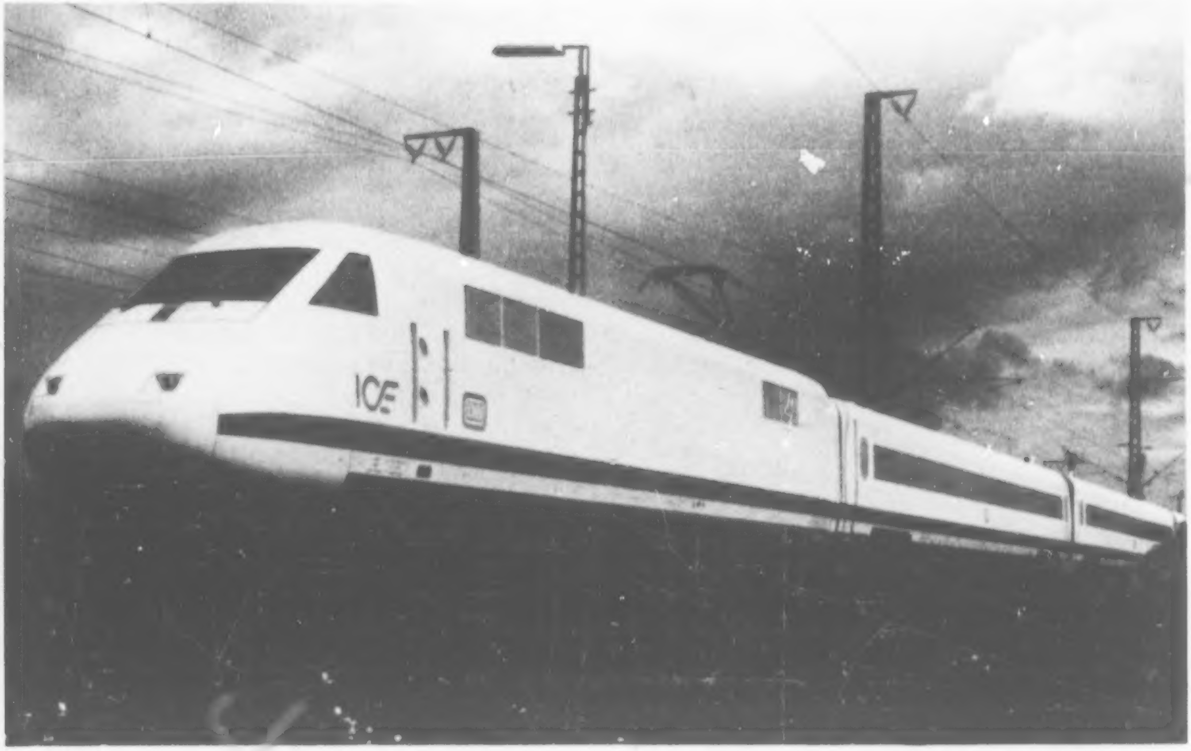

Photo credit: Deutsche Bundesbahn

The German Intercity Express (ICE) began operations in June 1991.

ductions for superconducting magnets and magnetic shielding. High-speed maglev concepts that incorporate many branch lines will require further development of switching technology. High-speed rail R&D issues include braking capabilities, wheel/rail dynamics, and economically acceptable techniques for collecting current at speeds over about 200 mph.

Institutional Issues

Intergovernmental Arrangements

Should the decision be taken to develop maglev technology, careful consideration must be given to how the development should proceed and who should undertake it. Different areas of technical expertise reside in various government agencies, private firms, and universities. A lead organization must be chosen or created to coordinate research on areas critical to maglev systems, ensure compatibility between system components, and, when appropriate, develop a strategy for testing prototypes (including selection of test sites). At some point, a decision may have to be made regarding suspension and guideway configurations, since different maglev designs are mutually incompatible for network operations. It is estimated that full-scale maglev development costs would range from a minimum of $750 million to somewhat over $1 billion, most of which would go toward prototype and test facility design and construction.

Safety and Certification

Operational safety features of existing maglev prototypes as well as the zero-fatality rate of existing high-speed rail systems indicate that these technologies could potentially operate more safely than all other passenger modes. However, **the current U.S. safety and regulatory framework for railroads cannot be directly applied to maglev and high-speed rail, and needs major reformulation. FRA must ensure that it has sufficient technical and administrative expertise for this task.** At present, for example, track standards for steel-wheel technology cover only speeds up to 110 mph. Current FRA and Association of American Railroads practices governing traffic control, track standards, and crashworthiness are based on the assumption of mixed passenger and freight traffic. Dedicated rights-of-way for passenger traffic, which are practically a necessity for high-speed systems, require a rethinking of current regulations. **A new total system safety approach must be developed for high-speed rail and maglev. A separate safety evaluation process for different types of vehicles (transit, mixed passenger/freight, dedicated, passenger-only high-speed rail), somewhat like the case in aviation, may be warranted.**

No matter how developed the technology, maglev or high-speed rail systems must gain public acceptance and be publicly financed in order to be built. A typical line could fall under many different State and local jurisdictions, complicating the regulatory and finance picture considerably. Siting the right-of-way, noise, and electromagnetic fields are the factors likely to cause the greatest concern, and each must be effectively mitigated if new systems are to stand any chance of being built. Technology demonstration and validation will be crucial in gaining public acceptance of a new system. Since private backing for new systems has been inadequate to cover initial costs fully, some combination of financial and institutional public support will be necessary for capital costs. Public sector support is essential if substantial R&D is to be conducted domestically.[34]

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[34] For further information, see Arthur D. Little, Inc., *An Industry Perspective on Maglev*, DOT/FRA/ORD-90/07 (Washington, DC: U.S. Department of Transportation, June 1990).

CHAPTER 5

Federal Policy Issues for Maglev and Tiltrotor

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CHAPTER 5

Federal Policy Issues for Maglev and Tiltrotor

Although new technologies, including magnetically levitated (maglev) vehicles and tiltrotor aircraft, are being developed that could help make our transportation system work better, these new technologies alone will not resolve current congestion and environmental difficulties. Transportation problems are due more to investment, land-use, and management policies and practices than to inadequate technologies,[1] and any technology change must be accompanied by appropriate policy changes, or the benefits may not be realized.[2] Furthermore, changes by any group of users, such as airlines or automobile commuters, to optimize their operations within a new policy and technology framework are difficult to forecast but likely to alter the long-term impacts of technology-based standards and policies.[3]

This study outlines the roles that maglev, tiltrotor, and other advanced technologies could play in improving intercity transportation. Tough decisions about complicated policy and transportation management issues must be made before development and operation of the technologies can proceed on a large scale in the United States. Moreover, a significant realizable market for these systems does not now exist domestically. Appendix B summarizes general conclusions on transportation system management, research, and technology from a recent OTA study. This chapter addresses the specific issues that affect the viability of tiltrotor and maglev.

Findings

- Maglev and tiltrotor concepts are technically feasible. Prototype vehicles have operated in the United States or abroad for more than a decade. Once installed, these new modes could operate at speeds that would provide door-to-door trip times competitive with conventional air transport at distances up to 500 miles. Maglevs and tiltrotors could avoid airport ground access and runway delays and offer terminals closer to population or industrial centers. If the maglev or tiltrotor vehicles depart as frequently as airliners, they could save time compared with travel by conventional air on a particular route. Developing tiltrotor or next-generation maglev systems to the point of being commercially viable would cost billions of dollars.

- Neither technology has been demonstrated as practical for intercity passenger service and the realizable market for tiltrotor or maglev technologies is subject to a variety of factors whose impacts are difficult to predict. The busiest air travel routes are the primary target markets cited by both maglev and tiltrotor proponents. However, potential entrepreneurs will face significant community and institutional barriers (see table 5-1) to establishing new transportation systems, and such issues are time-consuming and potentially costly to resolve. Moreover, if an intercity maglev, tiltrotor, or high-speed rail system is put into place, their operators will have to compete with the marketing power and pricing flexibility of the large airlines.

- Furthermore, maglev and tiltrotor systems will be expensive to establish—tiltrotors would cost more per seat to purchase and operate than conventional airplanes, and maglev routes would need 3 to 5 million passengers per year just to cover a 20-year amortization cost of the guideway at typical air travel fares. **Thus, time-sensitive service, such as business travel, is likely to be the initial market niche for maglev and tiltrotor, if most of the capital and operating costs are to be covered by ticket sales. It is not clear that either**

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[1] U.S. Congress, Office of Technology Assessment, *Delivering the Goods: Public Works Technologies, Management, and Financing,* OTA-SET-477 (Washington, DC: U.S. Government Printing Office, April 1991), p. 129.

[2] Ibid., p. 33.

[3] Ibid.

Table 5-1—Steps Still Needed for Operational Maglev or Tiltrotor System

	Commercial tiltrotor	Maglev
Technology development	Military V-22 program engineering and operating experience; noise, flight path, and cockpit research.	Debate revolves around whether to develop new U.S. designs or develop or buy foreign concepts. Low-cost guideways and reliable switches are desirable.
Infrastructure	Conveniently located vertiports; terminal airspace, routes, and procedures; air traffic control (ATC) and navigation facilities.	Available and affortable rights-of-way; dedicated guideways, bridges, grade separations, electrification, communication and control systems, and stations.
Technology and safety demonstration	ATC compatibility; community noise levels; economic data; airline and passenger acceptance.	Construction methods; construction, operating, and maintenance cost data; community and passenger acceptance.
Federal regulatory structure	Mostly exists—specific airworthiness and operating standards for tiltrotors are being developed. Initial vertiport standards have been published.	Not yet developed—some maglev design and performance characteristics conflict with current Federal Highway Administration (FRA) regulations. FRA is assessing the applicability of current statutes and regulations to the Orlando maglev and developing waivers, guidelines, and possibly new regulations for the project. The Orlando project will be the basis for future maglev regulations.
Legal and environmental concerns	Noise standards; local zoning.	Noise during very high speeds; right-of-way agreements; possible health effects of electromagnetic fields.
Financing	Under existing policies, Federal support for infrastructure possible but not for aircraft development.	No Federal policy for funding maglev or high-speed rail technology development or infrastructure.
Competitive framework	Airline cooperation is essential for tiltrotors to operate. Individual airlines have well-established operations in highly competitive short haul markets and see mostly risks and no additional profits in employing tiltrotors. The higher direct operating costs of tiltrotor service might have to be underwritten if tiltrotors are to provide public benefits of expanded airport capacity and reduced delays and congestion.	Airline marketing power and large, established route structure could be strong assets or formidable opponents to intercity maglev. Amtrak has operating authority for most routes proposed for passenger-carrying maglev or high-speed rail.

SOURCE: Office of Technology Assessment, 1991.

of these types of services will provide enough relief for intercity congestion and delays to serve as a cost-effective investment for Federal transportation dollars. However, without some public willingness to finance infrastructure, neither technology will be realized as an option.

- Tiltrotor and maglev could enhance other transport operations, in addition to intercity commercial travel, and might warrant Federal support. While tiltrotor has been developed primarily for military missions, it might also fill other public roles, such as emergency evacuation, or serve industry needs, such as offshore oil rig support. Maglev carries passengers on short, low-speed transit lines in Germany and England, and regional transit or commuter service might be feasible if maglev's potential for low maintenance costs is achieved.

- Congress will need to clarify objectives for funding these technologies. Research, development, and demonstration investments for maglev and tiltrotor technology could be considered to support long-term strategic purposes, such as technology leadership and future mobility. Tiltrotor, maglev, or other new transportation technologies could be cost-effective in certain locations if conventional options become insufficient or too expensive to meet future transportation needs. How maglev or tiltrotor development would affect the domestic economy or balance of trade depends on a variety of factors.

- Some form of Federal financing will be required if commercial maglev or tiltrotor technologies are to be developed by U.S. industry in the next decade. Foreign high-speed rail technology is available now for U.S. markets, and German maglev will be ready by late 1992. Public support for infrastructure—rights-of-way for maglev and specific air traffic control (ATC) and landing facilities for tiltrotor—would also be necessary, regardless of who advances and sells the technology.

- Developing maglev or tiltrotor technology and establishing operating systems in the next 10 to 15 years to help improve conventional transportation modes will need complementary Federal environmental, intermodal, and transportation management policies. Most forecasts project that passenger travel will continue to grow during the next 20 years, although future congestion levels are difficult to assess. For example, airline scheduling strategies rather than passenger demand determine how crowded the runways at most hub airports become. If congestion increases, tiltrotor, maglev, and other alternative transportation modes might help relieve some pressure on highways and airports. However, under current market conditions and policies, too few passengers would switch to these new modes to effect much change in automobile or airline operations. Moreover, shifting traffic from highways or runways that are clogged is usually a temporary solution, since other vehicles quickly move into any newly created openings. **Executive branch agencies will face additional safety, environmental, and economic oversight and regulatory responsibilities that must be supported if maglev, tiltrotor, or other comparable systems are placed in service.**

- If the Department of Defense (DOD) V-22 *Osprey* program is continued, enough engineering and operational experience might be gained for industry and investors to make firm decisions, either pro or con, regarding commercial tiltrotor production. Industry observers believe that the V-22 design is unacceptable for most commercial transport applications, owing to economic and civil performance penalties inherent in meeting military requirements, although some V-22 structural and propulsion designs and components might be directly transferable to a commercial tiltrotor. **Because it has worked closely with DOD to collect data from the V-22 flight test program, the Federal Aviation Administration (FAA) is well positioned to certify a V-22 type of aircraft for civilian test and demonstration operations by late 1995, if a sponsor requests it.**

- The Federal Railroad Administration (FRA) has just begun developing a regulatory framework for maglev. That agency will be especially challenged by the decision to place maglev in service in Orlando, Florida, by the summer of 1995. FRA's technical and regulatory framework for maglev and other high-speed systems needs bolstering, regardless of where the technology is developed. Ensuring the safety of high-performance and technologically complex maglev systems may require more active oversight procedures, including a system safety approach for approving designs and Federal licensing of operating companies and personnel. **In the interim, FRA must continue collecting and analyzing data from foreign high-speed rail and maglev operations. Additionally, FRA's safety research and development (R&D) resources, strained by the workload of the current National Maglev Initiative (NMI), will have to be strengthened to monitor and participate effectively in a full-scale maglev technology development program and in the implementation of high-speed rail systems now being considered by various States.**

Options for Research and Development

The U.S. military is testing tiltrotor aircraft, Japan and Germany are developing maglev technologies, and a Japanese company plans to produce small tiltwing[4] aircraft by 1997. These designs would be costly to establish and unlikely to penetrate the intercity passenger markets in the United States. Other concepts might prove more cost-effective. However, these or similar transportation technologies will likely be used on a small scale within the United States during the next 10 years, and the Federal oversight agencies will have to be prepared to evaluate such systems. At issue is the Federal role in fostering maglev and tiltrotor technologies for commercial applications and ensuring the safety of systems proposed for use in the United States.

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[4] The similarities and differences between tiltwings and tiltrotors are discussed in ch. 3.

Both maglev and tiltrotor could be included in a comprehensive Department of Transportation (DOT) research program into technological and system solutions to mobility problems. Maintaining a broad Federal transportation research base in these and other promising technologies, along with extensive data on passenger travel patterns, would assist in deciding on and gearing up for a larger scale development effort if conditions warrant it.

Foreign competitiveness implications of maglev and tiltrotor have been raised repeatedly in testimony to Congress, and Congress may consider making national leadership in either of these technologies an explicit goal. (The international context of such a technology policy goes beyond the scope of this study.) The United States has a significant worldwide lead in tiltrotor technology, and military, commercial, and public service applications have been identified for high-speed vertical takeoff and landing (VTOL) aircraft. Much tiltrotor technology development, engineering, and flight testing is directly transferable across the tiltrotor mission concepts, and other countries are seriously considering tiltrotor (or similar technology) programs. The extent of a global market is uncertain, but niche markets appear to exist. Therefore, the United States could have a favorable balance of trade in this product class if it is brought to market soon.

Things are different for maglev. Technology leadership is also an issue, but in this case Germany and Japan have the lead. German maglev could carry revenue passengers in the United States by 1995, and Japan has committed to spending $3 billion over the next decade to develop and test maglev technology. The world market for U.S.-produced maglev is uncertain. Most countries that could consider investing in maglev systems in the next two decades—Western European nations and Japan—have strong commitments to home-grown maglev and high-speed rail technologies. Even Germany, which invested substantial public funds to develop maglev, is implementing high-speed rail, not maglev. However, if enough Federal support is available to develop one, a U.S. maglev system could compete for these markets over the long term or in regions elsewhere in the world.

If Congress wishes to regard the trade balance as an issue affecting maglev, the complexities need to be closely examined. The largest component of a maglev is infrastructure—rights-of-way, guideways, and stations—and infrastructure is generally not exportable. Regardless of where the technology originates, 75 to 90 percent of the expenditures would go to construction and engineering firms that put the maglev infrastructure in place. U.S. firms could compete for this construction in foreign countries, but a government often gives preference to domestic firms. In addition, any government is likely to prefer vehicles to be produced domestically if a large enough market exists.

Tiltrotor Development Priorities

Policies and an institutional framework currently exist for Federal R&D for aviation, and a dedicated funding source, the Aviation Trust Fund, exists to support technology and infrastructure development to expand system capacity. Technologies that enhance safety and community acceptance are fundamental needs of all civilian VTOL aircraft—helicopters, tiltrotors, or others—and developing such technologies for aircraft and infrastructure falls within the purview of existing National Aeronautics and Space Administration (NASA) and FAA programs. However, substantial Federal funding for developing and testing tiltrotor technology would be necessary, on the order of $250 million over a 3-year period, if U.S. industry were to decide in the near future to produce commercial vehicles. Congressional approval would also be required. If Federal efforts in civil tiltrotor technology development are to continue or increase, the priorities are:

Continue Vertical Flight Research at NASA and FAA, Including Certification and Regulatory Support—NASA and FAA conduct about $27 million annually in research activities, mostly advancing civilian and military helicopter operations. About $5 million goes specifically to tiltrotor investigations. FAA is also collecting engineering and test data from the V-22 flight test program, which will assist future certification work for tiltrotors and other advanced VTOL concepts. Because of the potential quantum jump in performance over conventional helicopters, consideration might be given to increasing the percentage of vertical flight research funds devoted to high-speed VTOL concepts.

Step Up Work on Vertical Flight Research To Address Issues Affecting Public Acceptance—Congress could encourage FAA and NASA to conduct R&D that would make VTOL aircraft and infrastructure more attractive to communities and airlines. The most important program goals are to improve rotor designs to reduce noise, ensure appropriate cockpit equipment and procedures, and to develop flight tests and any necessary equipment to permit the steep flight paths to and from landing facilities. Closer coordination than has been customary would be required between NASA and FAA if such programs were instituted. One way to effect this would be to establish an advisory committee with an explicit charter to integrate the agencies' efforts. Such a committee could also be empowered to help set priorities for other current vertical flight R&D programs.

Test and Demonstrate Tiltrotors in Civilian Operations—Tests and evaluations of tiltrotors in civilian/commercial operations, which would also aid in gaining community and airline acceptance and in verifying infrastructure requirements, will be essential before manufacturers will commit to commercial tiltrotor production. At a minimum, Federal support for tiltrotor demonstrations would include standard regulatory and ATC functions and providing XV-15 and V-22 tiltrotor vehicles. Operational demonstrations of civil aircraft straddle the line between long-term technology development and near-term commercial goals—the full Federal role is unclear. Unless Congress commits to and funds a national civil tiltrotor program, operational testing might be accomplished at best gradually with funding out of NASA and FAA vertical flight R&D budgets. However, without an established funding profile, larger tasks, such as quiet rotor design and flight validation, will not be taken on. An intensive 3-year tiltrotor research and demonstration program, as described in the NASA/FAA Civil Tiltrotor Missions and Applications study,[5] would cost, on an annual basis, two or three times the amount currently allocated for all NASA and FAA vertical flight programs, or $60 million to $90 million per year.

Maglev Development Priorities

Maglev, high-speed rail, and other advanced surface transportation modes need to be considered together and in conjunction with possible implementation options. Since high-speed rail is a fairly mature technology and operational overseas, it is unclear that an economic advantage would come from Federal investment in developing new steel-wheel technologies. However, technology and infrastructure research efforts to aid in establishing new routes in the United States would have immediate impact, since high-speed rail vehicles are available now.

If its promise is realized, maglev will travel faster and cost less to maintain than high-speed rail. Congress supported the National Maglev Initiative, a 2-year, $25-million program to evaluate the role maglev can play in the U.S. transportation system and to recommend further actions regarding R&D for a U.S. maglev system. The three-agency NMI team—DOT, the U.S. Army Corps of Engineers, and the Department of Energy —is to report its findings in late 1992. The Transportation Research Board is investigating possible applications of high-speed surface transportation systems in the United States and expects to release its results this year. If Federal efforts in maglev technology development are to continue or increase, the priorities are:

Complete the National Maglev Initiative—Fund the program through its scheduled conclusion at the end of fiscal year 1992. Since the results of the NMI study will not be available for fiscal year 1993 transportation appropriations deliberations, Congress may wish to provide follow-on funding for the transition year for the most promising Federal efforts as it decides the near-term Federal role in maglev technology development. The results of NMI investigations will help in evaluating foreign maglev performance and are essential for deciding whether or not to commit major public funds for a U.S. maglev program.

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[5] Boeing Commercial Airplane Group et al., *Civil Tiltrotor Missions and Applications Phase II: The Commercial Passenger Market*, prepared for National Aeronautics and Space Administration and Federal Aviation Administration, draft final report, NASA CR 177576 (Seattle, WA: February 1991), ch. 7.

Address Maglev, High-Speed Rail, and Similar Systems in Related R&D Programs When Possible—Research efforts to reduce the costs of materials and construction and limit the environmental effects of major infrastructure projects are critical to the future of new ground transportation systems in the United States. Research into communication and automation technologies may be relevant for maglev and high-speed rail operations, and understanding the health effects of electromagnetic fields is important for the future of all electrically powered transportation systems. Specific technology needs differ markedly between the two basic types of maglev and between them and high-speed rail.

Bolster FRA Regulatory Framework—Regardless of near-term decisions on U.S. maglev programs, an appropriate Federal regulatory framework will be essential for overseeing the safety of maglev and similar technologies. FRA has traditionally depended on industry to develop design and operating standards for rail. **Congress may wish to encourage FRA to evolve new regulatory oversight policies and R&D programs to support this development over the long term and to develop institutional expertise to address maglev technologies. This is a top priority, since suitable regulations, operating standards, and safety R&D programs for maglev and high-speed rail do not presently exist at FRA.** Technical and regulatory expertise at the Urban Mass Transportation Administration, the Volpe National Transportation Systems Center, and FAA could assist FRA, and some standards and regulations already in place in other countries might be utilized.

Establish an Institutional Framework for Maglev Development—If Congress decides to fund further maglev technology investigations, it must select a Federal agency to lead the effort. Unlike aviation, for which NASA and FAA have well-established roles and funding for technology research, the home for maglev research is not as clear. The Rail Safety Improvement Act of 1988 designates FRA as the lead agency for maglev, but R&D funding within FRA has dwindled in the past decade and the agency would be hard-pressed to undertake a large-scale maglev development program in the near future.

For the ongoing NMI, each of the three member agencies has brought unique and valuable perspectives to the program. This partnership will be useful if Congress decides to continue low-level investigations without committing to a major technology development effort. But a large-scale maglev development program might call for a different institutional structure. Because maglev has applications and consequences across transportation modes (urban and airport transit, for example), DOT is a logical choice for Congress to designate to administer maglev development.

Test and Demonstrate Maglev Technology—Maglev vehicles and guideways, unlike the vehicles and infrastructure in other transportation modes, are intrinsically linked. For example, the German and Japanese prototype maglev vehicles can operate only on their own unique infrastructure.

Without a "standard" maglev guideway, technology testing will require separate facilities for each maglev configuration considered. Any research program, such as a post-NMI effort, must be crafted carefully so that a range of components and concepts can be studied at modest expense through the prototype stage, where significant further investment driven by infrastructure needs would be necessary to test and demonstrate vehicle operations. Moreover, because of the expense involved, large-scale testing and demonstration of U.S. maglev technology might have to be linked to a commitment to implement an operational system.

Options for Operational Implementation

Establishing new transportation systems is fundamentally a process of overcoming a series of barriers. Success may not depend on the inherent strength of a specific technology, or even the particular mode. Choices depend on public objectives and how active Congress wishes to be. The most pressing transportation problems call for changes in infrastructure investment and system management policies.[6]

If Congress decides that having an operating intercity maglev[7] or tiltrotor system in the next 10 to 15 years is an important goal, it will have to support the development of these technologies because neither system is yet perfected. The policy choices for operational implementation depend little on who develops the technology, although technology leadership often allows the home country to set standards, criteria, and procedures for applications.

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[6] Office of Technology Assessment, op. cit., footnote 1, p. 130.

[7] The Orlando system will not be an intercity route, and Texas is considering high-speed rail, not maglev.

Issues for Implementing Alternative Transportation Systems

In deciding whether alternative technologies are necessary for meeting future transportation needs, Congress must consider that new collateral policies for existing transportation modes may be required for ultimate success. Environmental or congestion management efforts might be required to help shift traffic to an alternative mode. Transportation infrastructure is costly and usually needs public support. Moreover, health, safety, and environmental guidelines and regulations for transportation operations are usually Federal responsibilities, although States and local governments can establish more stringent requirements.

Installing maglev and tiltrotor systems would expand overall mobility considerably. As other transportation modes—particularly highways and airports—become more congested, these additional transportation choices and increased capacity will become more valuable. Current data indicate that ticket prices higher than now charged by most airlines will be necessary if revenue from fares alone must cover full costs for establishing and operating these systems. Experience tells us that passengers are not likely to switch voluntarily from their current travel mode choices unless the value of time savings or other factors outweighs higher fares and any other extra costs. Congestion levels for highway and air travel might rise enough to make the higher relative costs for maglev or tiltrotor more attractive to consumers if no unforeseen changes in travel habits or technologies occur in the meantime.

Although each transportation mode offers advantages over the others in certain areas, overall system benefits, such as congestion reduction or energy/environmental gains, will not occur without additional, collateral policy changes. Significant latent demand usually exists for transportation infrastructure where substantial congestion occurs, and plenty of new conventional transportation service providers would be pressed to fill the vacancies left by any who choose to switch to maglev or tiltrotor. Additionally, Congress must consider whether a new system is to provide premium service only or to offer more affordable mass transportation, in which case additional public support may be necessary. Another question that needs to be addressed is whether a new transportation mode that vies for airline or highway passengers should be protected from anticompetitive practices. (Characteristics of some air and rail transportation modes are compared in table 5-2.)

Tiltrotor Operating System Options

Federal efforts to foster tiltrotor operations will enhance vertical flight in general, and may be considered part of a broader policy framework. However, higher performance vehicles, such as tiltrotors and tiltwings, may prompt changes in ATC and landing facility infrastructure independent of other rotorcraft needs. Several steps are necessary for successful commercial vertical flight in the United States.

Support Infrastructure Development—Some of the air and ground infrastructure necessary for tiltrotor operations can be developed before commercial tiltrotors are available. Federal funds and policies already support public airfield construction and improvement, and any facilities built with tiltrotor in mind would be capable of serving most civilian rotorcraft. However, current funding guidelines do not address heliports built to tiltrotor standards, since civilian tiltrotors are not yet a certainty. Some communities that are planning heliports want them suitable for future needs, and suitable guidelines could be developed. For the marginal cost of meeting tiltrotor standards, it is prudent to build vertiports at locations where there is public support for them and public heliport construction is planned. Congress may wish to encourage FAA to clarify the present policy on vertiport funding.

Table 5-2—Intercity Transportation Technology Comparisons for the Northeast Corridor (NEC)

	Jetliner (128-seat B737-300)	Tiltrotor (39-seat nonmilitary)	Maglev (200-seat Transrapid)	High-speed rail (350-seat TGV)	Conventional rail (350-seat Metroliner)
Performance:					
Maximum speed	550 mph	350 mph	250 mph	185 mph	125 mph
Total trip time one-way between DC and NYC[a]	3.2 hr	1.9 hr	2.6 hr	3.0 hr	4.1 hr
Energy consumption[b]	50-70 seat-miles per gallon (smpg)[c]	30-35 smpg	250 smpg	300 smpg	200 smpg
Economics: (for 10-million annual passenger trips in the NEC)					
Vehicle capital costs	$1.1 billion for 37 aircraft	$1.4 billion for 117 aircraft	$0.2 billion for 25 vehicles	$0.5 billion for 20 trainsets	$0.4 billion for 29 trainsets
Infrastructure capital costs[d]	Minimal new construction needed to handle NEC passengers[e]	$0.5 billion for 12 vertiports	$7.2 billion for new guideway system[f]	$3.6 billion for new rail system[g]	$2.0 billion to upgrade rail system between Boston and NYC
Vehicle operating costs[h]	7.1 cents per seat-mile	12.6 cents per seat-mile	3.4 cents per seat-mile	4.3 cents per seat-mile	4.9 cents per seat-mile

[a] The total time to travel door-to-door from origin to destination is most important to time-sensitive passengers. Each traveler could experience different delays (e.g., ground access, waiting at the terminal, mechanical difficulties) on each trip. The following assumptions were made for 1) average vehicle speed and 2) typical combined ground access and delay time for the calculations shown in the table. Vehicle speed/access and delay—jetliner: 355 mph/149 minutes; tiltrotor: 310 mph/72 minutes; maglev: 200 mph/90 minutes; high-speed rail: 150 mph/90 minutes; Metroliner: 90 mph/90 minutes. Jetliner and tiltrotor estimates come from the NASA/FAA civil tiltrotor study: Boeing Commercial Airplane Group et al., *Civil Tiltrotor Missions and Applications Phase II: The Commercial Passenger Market*, prepared for National Aeronautics and Space Administration and Federal Aviation Administration, NASA CR 177576 (Seattle, WA: Boeing Commercial Airplane Group, February 1991); calculations for ground access and delays for rail and maglev come from: John B. Hopkins, "Innovative Technology for Intercity Passenger Systems," *Passenger Transportation in High-Density Corridors* (Cambridge, MA: Volpe National Transportation Systems Center, November 1990), p. 44. The distance between Washington, DC, to New York City is roughly 200 miles; actual travel distance depends on terminal locations and routing.

[b] Energy use by each mode converted into equivalent gallons of jet fuel.

[c] Fuel efficiency of 75 to 100 smpg is feasible for new jetliners entering service after the year 2000, the earliest time that intercity tiltrotor or maglev could be established.

[d] Infrastructure for conventional aircraft and train service exists. Tiltrotors could use current airways and air traffic control (ATC) facilities, but would need new landing areas for optimal service. Maglev and high-speed rail require new guideways and supporting infrastructure; the calculations in the table assume 450 miles of new guideway for maglev or high-speed rail.

[e] Origin-to-destination air travel between the major airports in Washington, DC, Philadelphia, New York, and Boston presently accounts for around 10 percent of the total passengers and aircraft operations at those airports. Other air travel demands will be the major factors affecting airport and ATC infrastructure.

[f] Infrastructure for maglev, high-speed rail, and conventional rail include guideways, bridges, grade separations, electrification, signal/communication systems, and stations. The costs for a Transrapid maglev guideway system have been estimated at $10 million to $40 million per mile; $16 million per mile is assumed in the table.

[g] The capital costs for a new high-speed rail guideway system have been estimated at $4 million to $30 million per mile; $8 million per mile is assumed in the table.

[h] Includes crew, fuel, vehicle maintenance, and vehicle financing (15 years with 8.5-percent interest with semi-annual payments). Does not include vehicle insurance and indirect operating costs such as passenger and baggage handling, sales, administration, real estate maintenance, and liability insurance. Assumes 3.4 billion seat-miles per year.

Table 5-2—Intercity Transportation Technology Comparisons for the Northeast Corridor (NEC)—Continued

	Jetliner (128-seat B737-300)	Tiltrotor (39-seat nonmilitary)	Maglev (200-seat Transrapid)	High-speed rail (350-seat TGV)	Conventional rail (350-seat Metroliner)
Infrastructure amortization[i]	Not calculated[j]	1.3 cents per seat-mile	18.2 cents per seat-mile	9.1 cents per seat-mile	5.0 cents per seat-mile
Miscellaneous:					
Infrastructure use	Multiple operators of all aircraft types can use conventional airports	Multiple operators of most vertical takeoff and landing aircraft could use vertiports	Maglev guideways limited to specific vehicles; more than one common carrier per route feasible	High-speed rail tracks suitable for most nonfreight trains; current routes are restricted to single operators	Tracks are used by a wide range of trains, including local commuters
Other uses for vehicles	Military, corporate	Military, corporate, public service	Transit, commuter, airport connector	Airport connector	Commuter
Worldwide technology leaders	United States, Western Europe	United States	Germany, Japan	France, Germany, Japan	Europe, Japan, North America
Federal regulatory status	Well established	Within current framework; specific guidelines available	Existing rail regulations conflict with maglev characteristics; new guidelines are being developed	Some conflict with current rail regulations	Well established

[i] Amortization over a 20-year period with 6-percent interest and semi-annual payments; 3.4 billion seat-miles per year. Infrastructure operating and maintenance (O&M) costs are not included in this table. These costs are difficult to compare among different transportation modes as some infrastructure O&M costs are paid with public revenues and others are covered by private resources.

[j] Airport and ATC infrastructure cost billions of dollars to put in place. However, unlike the other transportation systems listed in this table, jetliners would not require new infrastructure to serve the NEC at the trip times indicated. See footnote e.

SOURCE: Office of Technology Assessment, 1991; and as stated in footnote a.

Some ATC procedures and technologies being developed by FAA for helicopter operations will also serve tiltrotors and tiltwings. Steeper approach paths[8] desired for tiltrotors, tiltwings, and commercial helicopters can be investigated with simulators and tested with available prototype aircraft and ground facilities, ensuring that a technically capable infrastructure could be in place for initial operators of advanced VTOL aircraft.

Establish Safety and Environmental Criteria—FAA is developing basic airworthiness and operating criteria for powered-lift vehicles (tiltrotor is one type of powered-lift) and is collecting V-22 data. These efforts should be continued and completed. Noise standards and guidelines for tiltrotors must be completed to aid in vertiport planning.[9]

Establish a Competitive Framework to the Extent Feasible—If a suitable vertiport network is put in place, tiltrotors may be able to compete on an equal basis with jet shuttle or other modes, and the market will decide its success. Increased flights into the ATC system, changed noise patterns, and increased energy consumption must be balanced against the time savings and increased mobility for air travelers when considering public policies for intercity tiltrotor service. Moreover, tiltrotors could increase airport capacity and productivity if they replace small conventional aircraft on a one-to-one basis and open runway slots for larger airplanes. Since tiltrotors are more expensive to operate than similarly sized commuter aircraft, airport feeder service may have to be subsidized in some form if tiltrotors are to replace commuters. One option is to use a common fund, such as the Aviation Trust Fund or an airport-specific account, to pay the cost differential for any operator who replaces a conventional aircraft with a tiltrotor if the public benefits justify it. While a major airline could gain from access to a new runway slot and might be willing to cross-subsidize tiltrotors out of fare revenues, it would have to be assured access to specific landing slots. Airline control of runway slots, however, remains a contentious issue. Any competitive market changes by airlines will also change the framework for tiltrotor.

Maglev Operating System Options

If Congress wishes to promote intercity rail and maglev operating systems, there are steps it could take regardless of whether or not a specific technology is favored.

Establish a Right-of-Way Policy—Available and affordable rights-of-way are key to maglev and high-speed rail operational feasibility. Use of the median strips, shoulders, and air rights of interstate highways is one possibility considered for maglev. General support for intermodal use of interstate highways is being deliberated in current surface transportation reauthorization legislation, and Congress needs to resolve existing Federal statutory restrictions, which now require full reimbursement for use of interstate rights-of-way. However, it is unclear to what extent a high-speed surface transportation system could use highway rights-of-way laid out for speeds of 70 mph.

Establish Infrastructure Financing Policy—Unlike that for highways, transit, water transportation, and aviation, there is no Federal program for financing infrastructure for intercity maglev or high-speed rail, and thus extensive maglev or high-speed rail systems are unlikely to be built unless this policy is changed. Current State transportation funds are committed mostly to highway programs, although some States might be willing to offer tax advantages to help finance maglev or high-speed rail systems. Flexible use by States of current Federal surface transportation allocations is another possibility. A separate program of matching State support for high-speed rail or maglev systems is also an option. While small-scale State initiatives might be considered independent of specific technology, any financial commitment to a maglev system on a multistate or national scale requires an infrastructure standard for interoperability (i.e., like the interstate highway system). Various high-speed rail technologies, for the most part, can use common tracks. Differences are due mostly to maximum speed requirements.

Establish Federal Regulatory Guidelines for Maglev Safety—Since States turn to the Federal Government for guidance on rail safety oversight, FRA regulatory policy for intercity high-speed rail or maglev systems must be expanded before such systems can be built. FRA is working with the States of Florida and Texas in preparing for their new systems. This effort will have to be expanded in scope if either of these technologies is to be implemented on a national scale. Issues of dedicated rights-of-way for passenger traffic and full-system safety requirements dictate rethinking of current FRA regulations, and Congress could consider encouraging such a change at DOT.

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[8] Although current helicopters takeoff and land vertically, they now fly shallow approach paths similar to airplanes.

[9] Noise standards are established for helicopters (14 CFR 36) and heliport planning (14 CFR 150).

Establish a Competitive Framework—Maglev and high-speed rail would be new entries into the high-speed intercity transportation market, which is presently dominated by large airlines. Airline marketing power and large, established route structure could be strong assets or formidable opponents to intercity maglev or high-speed rail. It is unclear what effect airline or Amtrak decisions could have on the prospects for private financing of maglev or high-speed rail projects, and this issue needs further study. The ongoing Texas high-speed rail project should prove a valuable case study for Congress.

APPENDIXES

APPENDIX A
The Effects of Electromagnetic Fields

Electric and magnetic fields exist in the natural environment and are present wherever there is electric power. At lower frequencies and long wavelengths, the fields can be identified separately as electric and magnetic fields. At higher frequencies, where these fields are usually coupled, the fields are often referred to as electromagnetic radiation or non-ionizing radiation. Electric and magnetic fields are collectively called electromagnetic fields (EMF). EMF can include alternating current (AC), which produces oscillating electric and magnetic fields, and direct current (DC), which produces steady fields.

Because magnetic levitation (maglev) uses electric propulsion and onboard power capabilities, passengers are exposed to EMF. In addition, local residents and others close to the right-of-way are exposed to fields, although the magnitude drops off sharply with distance. These exposures are comparable to those from electric power transmission and distribution lines. Figure A-1 summarizes the field strengths encountered in maglev systems and common appliances. However, precise health risks associated with EMF exposure, if any, are not understood. Researchers are confident that high-intensity DC fields are detrimental to human health, and low intensities are now of concern, but the effects of AC fields and interactions between electric and magnetic fields are not well known. Much more research is required before conclusions can be drawn about the potential dangers to human health associated with frequent exposure to weak EMF, as typically encountered in home, office, and urban environments.

Possible health concerns include cancer, alterations in the central nervous system, and effects on the reproductive system. It has been determined that even low EMF can trigger certain biochemical responses critical to the functioning of cells. Of special concern to the transportation industry are possible EMF effects causing depressed melatonin production and shifts in circadian rhythms. These affect fatigue, alertness, and reaction time, and therefore are especially important for transportation workers. However, the magnitude of these responses, whether they are transient and reversible and their effects on overall human health, are not understood.

The lack of consistent data on human exposure to EMF pose barriers to any inferences about potentially harmful health effects. To compound the problem, consistent methods of measurement and modeling for EMF strengths, geometry, and frequency have not yet been developed.[1]

While it is clear that a maglev system will produce EMF, it is not known what, if any, health effects these fields would have on the system's passengers. In the early Japanese prototype maglev, superconducting magnets with very high-flux densities were used, resulting in high-strength DC magnetic fields in the cabin area (up to 350 gauss) without appropriate shielding. Passive shielding, incorporating ferrous or other special metals,[2] can combat this potential hazard, although light-weight shield materials are expensive and hard to obtain. The Japanese have recently redesigned the superconducting maglev vehicle to lower cabin exposure levels below a 10-gauss nominal level. Active shielding approaches, in which magnetic fields are purposely generated to cancel other magnetic fields, are another possible control measure.

The intensity of fields found adjacent to the right-of-way varies for different maglev designs, presenting potential new problems, since States have differing restrictions on permissible levels of DC and AC fields. Although the World Health Organization has published interim EMF guidelines for workplace exposure to higher frequencies, as of yet there is no national policy

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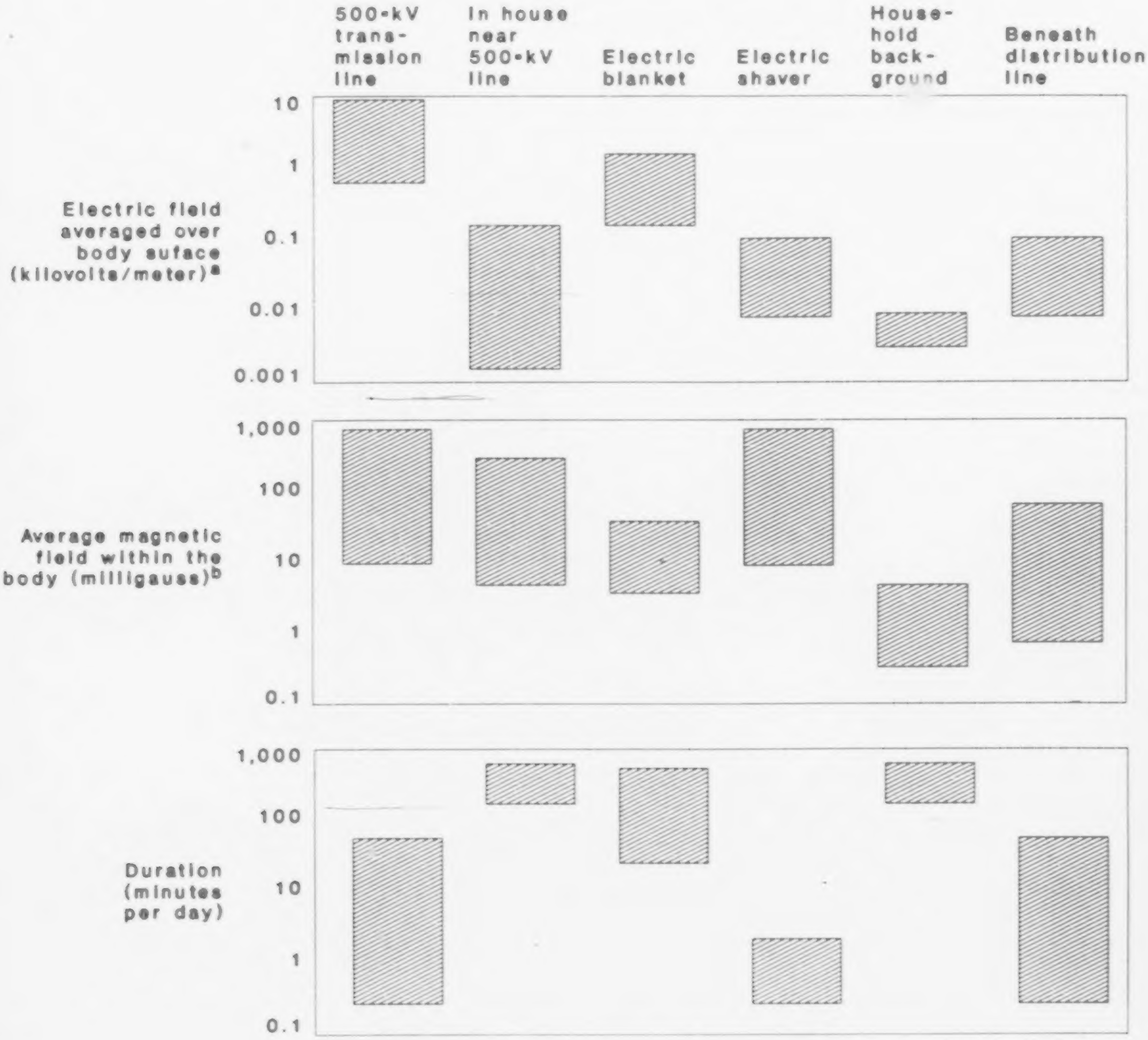
[1] For more information, see U.S. Congress, Office of Technology Assessment, *Biological Effects of Power Frequency Electric and Magnetic Fields*, OTA-BP-E-53 (Washington, DC: U.S. Government Printing Office, May 1989).

[2] Ibid., p. 16.

Figure A-1—Typical Electromagnetic Fields Under Everyday Conditions



SOURCE: Office of Technology Assessment, 1991.

on EMF exposure limits, and States are subject to interest group pressure to lower the allowable levels.

Maglev is not the only transportation system with potential EMF problems. Although no significant studies have been conducted on the subject, steel-wheel technologies, such as rail transit and intercity rail, which use a significant electrical power source, also create EMF. Because of the unknown health hazards of EMF, more studies and tests must be conducted before these systems are given final approval. Congress directed the Federal Railroad Administration (FRA) in the fiscal year 1991 maglev appropriations bill to adopt a safety research program to study and counter the potential problems associated with EMF in maglev and high-speed rail systems. FRA must develop safety and operating standards for maglev, address basic R&D questions (including superconducting magnets and magnetic shielding), and initiate a comprehensive research program to identify, characterize, and minimize potential health effects associated with magnetic fields generated by maglev systems. FRA, assisted by the Volpe National Transportation Systems Center, is undertaking a multiyear research and development program on health effects of magnetic fields associated with maglev and high-speed rail technologies under the 1990 National Maglev Initiative. The program will be integrated into a comprehensive system safety study of maglev and advanced rail concepts proposed for U.S. applications.

APPENDIX B

Federal Transportation Conclusions and Policy Options

Excerpted From "Delivering the Goods"[1]

In 1988, following a number of national studies calling in vain for more investment in public works infrastructure, the Senate Committee on Environment and Public Works asked OTA to identify ways to change Federal policies and programs to make public works more productive and efficient. The results of this study were released in April 1991 in the OTA report, *Delivering the Goods: Public Works Technologies, Management, and Financing*. Substantial portions of the report deal with issues that underlie tiltrotor and maglev and a few are excerpted and provided below.

Institutional Issues

Neither DOT [Department of Transportation] nor Congress has successfully overcome strong, separate modal interests and achieved an appropriate systems approach to solving transportation problems. In Congress, only the appropriations committees have sufficiently comprehensive jurisdiction, but those committees were never intended to set transportation policy. DOT's recently published National Transportation Policy recognized this and encouraged a multimodal approach toward transportation problems. However, this encouragement is not enough; OTA concludes that unless steps are taken to institutionalize a multimodal approach within DOT, the traditional modally oriented structure will be perpetuated and the agency will not be able to address today's transportation issues effectively.[2]

If the Federal Government is to regain a leadership role in transportation, changes in institutional management must be made. One way to effect change would be to create surface transportation programs that support intercity passenger, urban, and freight transportation, and connections to ports and airports. Over the longer term, options include restructuring DOT in divisions by broad mode—aviation, surface and water transportation—or by function, such as metropolitan passenger and intercity freight transportation. Reforming congressional oversight as well, by developing a mechanism to coordinate or concentrate transportation authorization, will be crucial to the success of a restructured DOT.[3]

Spending Priorities

Broadening categorical grant programs to permit greater flexibility on the part of local governments in using trust fund monies, especially for maintenance programs, is probably the best way to ensure that short-term capacity and condition needs are met. Next in importance are reshaping Federal policies to encourage fair pricing and efficient infrastructure use and to increase State and local spending to raise the total national investment. Making more Federal monies available for passenger and commuter rail and mass transit are options for improving the efficiency of transportation system use. Although commuter rail and transit have long been considered primarily regional or local services, a compelling case can be made for their importance to interstate commerce, since each represents an alternative way to increase highway capacity in urban areas. Congress could also permit States and jurisdictions to use surface transportation grant funds for mass transit and passenger and freight rail improvements, if doing so is a priority to their regional or State transportation system plans.[4]

For the longer term, an intensive Federal effort should be started now aimed at developing and implementing a strategic policy and research agenda for transportation to evaluate the tradeoffs of alternative ways to address overcrowded intercity corridors and urban traffic congestion. This program must have funding support and participation from all the transportation modal administrations and from the industries that will benefit.[5]

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[1] U.S. Congress, Office of Technology Assessment, *Delivering the Goods: Public Works Technologies, Management, and Financing*, OTA-SET-477 (Washington, DC: U.S. Government Printing Office, April 1991).

[2] Ibid., p. 132.

[3] Ibid., p. 132.

[4] Ibid., p. 26.

[5] Ibid., p. 27.

Support for Technical Innovation

Public works services are expected to be reasonably priced and reliable; they do not lend themselves to trial-and-error methods of selection. Local officials use tried and true technologies, because they do not have the analytical resources to assure the performance of a new technology and cannot afford the political or operational risk of failure. Thus, liability concerns haunt suppliers, manufacturers, and public officials as well, and manifold difficulties confront the developer of a new technology for public works. Many a technology entrepreneur is frustrated by rejection of his attempts to have his development tested, so a track record can be developed.[6]

Cooperative, joint efforts between private sector suppliers and government to demonstrate and evaluate new technologies for safety, durability, and long-term costs are excellent ways to spread the risk and overcome some of the difficulties of the procurement process for new technologies. OTA concludes that supporting such development and evaluation programs is an essential Federal function that has been inadequately supported in every public works field except aviation and water transportation. Increasing DOT investment in such programs for highways, mass transit, and passenger rail by 50 percent would bring substantial returns in improved public works performance.[7]

Management and Institutional Priorities for Research

As a result of budget cutbacks and the lack of coordination for [research and development] R&D over the past decade, each administration's R&D has become increasingly modally oriented and focused on supporting short-term program objectives. The lack of long-range and systems-oriented R&D has left DOT unprepared to address current national needs, such as transportation-related air quality issues and urban capacity issues. While the agency is attempting to make up for these shortcomings now, developing and implementing appropriate new programs and ensuring adequate funding are major challenges.[8]

While DOT provides direct support for regional transportation, it commits its resources on a modal basis, with R&D support heavily skewed toward [the Federal Aviation Administration] FAA and [the Federal Highway Administration] FHWA. Data collection on travel and shipping patterns has been neglected. As a result, alternatives to current and future transportation patterns are not pursued, and one outgrowth is the dearth of R&D on intermodal connections. Both public and private transportation officials have identified the lack of information about intermodal linkages, such as airport-ground and port-to-railhead access, as a stumbling block to developing policies that support growth and increased capacity. Revision of the current modally defined R&D is long overdue, and DOT needs to develop R&D programs to address intermodal needs and capacity enhancing transportation alternatives. Congress could require DOT to collect and analyze freight commodity and passenger flow data and to constitute and institutionalize a mechanism to ensure that all its R&D takes into account interdisciplinary and intermodal issues. Options include establishing a transportation data office or center, strengthening the R&D Coordinating Council, and creating an effective Secretary-level R&D coordinator.[9]

Federal public works R&D efforts tend to be low profile and are often overshadowed by the obvious problems of infrastructure upkeep and construction; R&D programs often fail to weather the first and deepest cuts when department-wide budgets shrink. In the short term, Congress may want to consider authorizing and appropriating agency R&D budgets on a separate line-item basis to guarantee executive agency commitment and greater financial stability for R&D programs.[10]

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[6] Ibid., p. 35.

[7] Ibid., p. 36.

[8] Ibid., pp. 219-220.

[9] Ibid., pp. 236-237.

[10] Ibid., p. 236.

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